CHACTERIZATION AND CLASSIFICATION OF SOME LOCAL FLY ASHES

A thesis
Submitted by

Alok Patel
(211CE1230)

In partial fulfillment of the requirements for the award of the degree of

Master of Technology
In
Civil Engineering
(Geotechnical Engineering)
Department of Civil Engineering

National Institute of Technology Rourkela
Odisha -769008, India
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DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA, ODISHA-769008

CERTIFICATE

This is to certify that the thesis entitled, "**CHARACTERIZATION AND CLASSIFICATION OF SOME LOCAL FLY ASHES**" submitted by ALOK PATEL bearing Roll No. 211CE1230 in partial fulfillment of the requirements for the award of Master of Technology degree in Civil Engineering with specialization in "Geotechnical Engineering" during 2011-2013 session at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or Diploma.

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Date: 29-May-13
Place: Rourkela

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ABSTRACT

Excavation of soil to use the top soil for road construction, earth dam construction, soil stabilization, backfill material, is a great matter of concern as it takes thousands of years to form the natural top soil. Due to soil excavation, deforestation occurs, which affects the bio-diversity. Industrial waste such as fly-ash, slag etc can be effectively used as alternate soil material. Utilization of fly ash is also a major challenge to the sustainability of thermal power stations and large scale utilization of fly ash in geotechnical constructions will reduce the problems of its disposal. As the properties of fly ashes vary from place to place; there is a need to check the variability of properties to for its effective utilization. Hence, before the utilization of fly ash as a construction material, it is necessary to study properties of fly ash from different sources, so that it can be used beneficially. In this present study, four fly ashes form local thermal power plants are considered. Several Geo engineering laboratory experiments were performed on these fly ashes to determine its properties. The experimental results of present fly ashes were compared with that available in the literature. The optimum lime content is found out in terms of unconfined compressive strength and is found to depend upon the source of fly ash. Using the classification scheme available in literature it was observed that all the four fly ashes considered here belong to the same class, but a wide variation in their properties is observed. Experimental results also showed strength, cohesion and friction are increased by stabilizing fly ash with lime. But the strength value and increase in stabilized value are also distinctly different for these four fly ashes. Hence, there is a need to consider an alternate classification scheme for fly ash for its effective utilization as a fill and embankment material.

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CHAPTER 1

Introduction

1.1 Overview

Fly ashes have close resemblance with the volcanic ashes. In early age volcanic ashes were used as hydraulic cements, which were made near the small Italian town Pozzuoli. Hence the term "pozzolan" was coined. That was one of best pozzolans used in the world.

Now-a-days, fly ashes are generated from coal fired electricity generating plant. With rapid industrialization, there has been an increase in production of fly ash. The power plants grind the coal mass to make it fine powder form, before it is burnt. The mineral residue left by burning coal is collected from exhaust gases by electro static precipitator and collected for use. The major problem of the whole process, of production of fly ash is their safe disposal and management. The waste generated from industries are complex characteristics and composition, hence it is necessary to safely dispose the wastes otherwise it will have a negative impact on environment and social life, which will ultimately disturb the ecological system. Proper treatment has to be made before the disposal and storage of the industrial wastes, otherwise it makes the soil and water contaminate.

The micro sized fly ash mainly consists of silica, alumina and iron. The fly ash particles are generally spherical in size, which makes them easy to blend and to flow, to make a suitable mixture. The capillarity is one of the best properties for fly ashes to add as admixture for concrete. The fly ash contains amorphous and crystalline nature of minerals. The properties of fly ashes vary timely, with complex variation in all chemical, physical and geotechnical properties, and for this it is necessary are need to study the properties of fly ash from different soureces.

1.2 Fly Ash Production And Disposal

Coal is used as a fuel, in thermal power plant for generation of steam. In past coal was used generated from the furnaces of boilers in the form of lumps. The old boiler proved to be non energy efficient, hence to optimize the energy efficient from coal mass, the thermal power plants used pulverized coal mass. The pulverized coal mass is injected into combustion chamber, where it burns instantly and efficiently. The output ash is known as fly ash, which consists of molten minerals. When the coal ash moves along with the flue gases, the air stream around the molten mass makes the fly ash particle spherical in shape. The economizer is subjected, which recovers the heat from fly ash and stream gases. During this process, the temperature of fly ashes reduced suddenly. If the temperature falls rapidly, the fly ashes are resulting amorphous or glassy material and if the cooling process occurs gradually, the hot fly ashes becomes more crystalline in nature. It shows that the implements of economizer, improves its reactivity process. When fly ash is not subjected to economizer, it forms 4.3% soluble matter and pozzolanic activity index becomes 94% [23] .When it subjected to economizer, it forms 8.8% soluble matter and pozzolanic activity index becomes 103% [23] .Finally, the fly ashes are removed from the flue gases by mechanical dust collector, commonly referred to electrostatic precipitator (ESPs) or scrubbers. The flue gases which are almost free from fly ashes are subjected to chimney into the atmosphere.

The ESPs have the more efficiency about 90%-98% for the removal of lighter and finer fly ash particles. Generally ESPs consists of four to six hoppers, which are known as field and the fineness of fly ash particles are proportional to number of fields available. Hence, if fly ashes are collected from first hopper, the specific surface area found to be 2800 cm^2/gm, where the collection is from last hopper, it is high about $8200cm^2/gm$[23]. The pulverized coal being burnt, 80% of coal ashes are removed from flue gases and it recovers as fly ashes, next 20% of coal ashes, if coarser in size, and then collected from bottom of the furnace. This material is called as bottom ash. This can be removed in dry form or it can be collected from water filled hopper, from the bottom of the furnace. When sufficient amount of bottom ash filled the hopper, it can transferred by water jets or water sluice to a disposal pond, where it is called as pond ash. Fig1.1 gives the idea of systematically idea of disposal of coal ash, in a coal base thermal power plant.

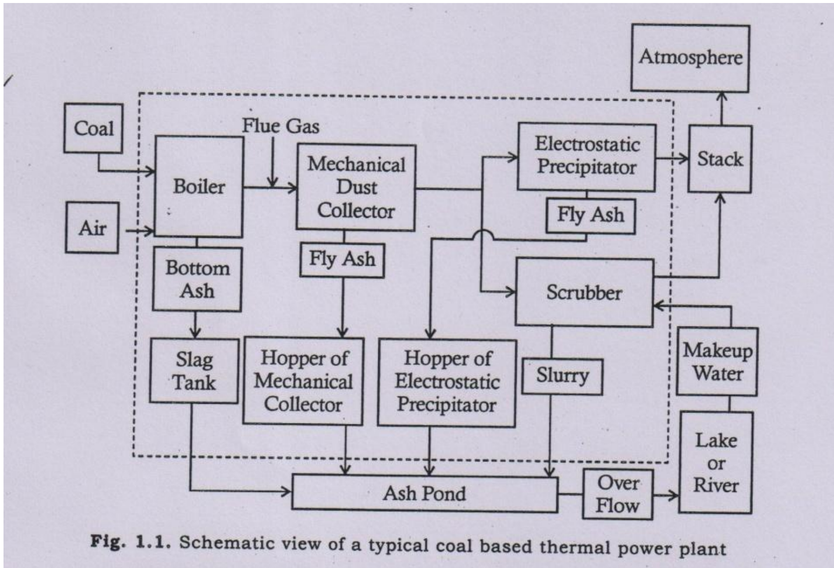


Fig1.1 Schematic view of a typical coal based thermal power plant

(data source Prakash and Sridharan 2007)

Disposal of coal is major environmental issue, because it pollutes the atmosphere and contaminate the ground water. The two way of disposal system are :

If the fly ash quality is good, then it is collected by ESPs and packed in moisture proof bags and finally transferred to other locations for other geotechnical use in embankments, cement industry like. If the quality is not good, then it adds to requisite moisture, to prevent the fly ash from the atmosphere. This process is called Dry disposal system.

Fly ash is subjected to water, and pumped to disposal site called as dyke. Dykes are constructed around the site or lagoon. The lagoons are filled with slurry, before switch to next slurry. Once the ash particles are settle, the water above is removed by natural ways. This process is called Wet disposal system.

1.3 How Fly Ash Is Hazaradous

Fly ash is hazardous due to its disposal problem. The method of disposed of fly ash and bottom ash in the form of slurry, in the ash pond is a long term method. The several problems occur during this process are:

When the ash ponds are full, then it requires several construction materials, so wastage of resources. When lagoons are full, then transferring of fly ashes from one site to another is difficult one. Raising the fly ash dyke by using construction material or excavate the fly ash dyke is problematic. The construction of ash pond requires huge amount of land, which deplete the valuable amount of agricultural land. When one fly ash dyke filled up, then construction of another dyke is not economical and wastage of valuable agriculture land. Large quantity of water requires making it in the form of slurry. During rainy seasons the salt and metallic content with the fly ash, leach to ground water and make it contaminated. Fly ash contains maximum amount of heavy metals and also unwanted substances, which cause health problem. Potentially toxic elements present in fly ashes are chromium, arsenic, cadmium, lead, nickel, zinc like this. If these materials go into human internal system, it causes toxic to cancer and damage of nervous system, like cognitive deficits, behavior problem and developmental delays. The fly ashes can also damage heart, respiratory distress, lung disease, reproductive problems and impaired bone development in children. If someone lives near unlined wet ash pond, then chances of getting cancer by arsenic contaminated water, if arsenic is one of the trace element in fly ash.

When coal ash come contact with ground water, the harmful elements leach and dissolve with water. The coal ash contains heavy elements leachate that seeps through ground water ways through streams, river and wetlands and also into the aquifers, which supply drinking water. This causes the people, to supply new drinking water. The fly ashes toxic elements also travel to the environment, by runoff and erosion and through the air medium. Another way fly ash is fine powder material and travel in air, if not properly disposed; it pollutes the air and water, which cause respiratory problem. It also settles in crops and leaves, which cause lower yield. Hence, it is necessary to check the fly ash properties, for its utilization.

1.4 Variability Of Fly Ash Properties

The variability of fly ashes depends on many factors like coal deposits geology, methods of control and burning of combustion process, additive use for flame stabilization, hopper position, number of hoppers, corrosion control additives used, dynamic flow of precipitator, and efficiency of pollution control instrument. But mainly the characteristic of fly ash is affected by the type of coal from which it is derived. Coal is formed by carbonaceous rock deposit, accumulated vegetable matter, which changes its composition under the influence of temperature, pressure and time over millions of year past. Hence, coal varies widely in its chemical composition. Based upon origin of formation of coal, different source of coal supply varies with different grade. General grade of coal are Grade A, Grade B, Grade C, Grade D, Grade E, Grade F are available. Coal supply to power plants Kalunga, NTPC, TTPS and NALCO are categorize under grade E or F type of coal.

Each grade of coal is different from each other with respect to their method of supply and chemical composition. Hence, according to that, fly ash properties are also varying with different sources. Exposure to atmosphere the properties of fly ashes are also different from the same source with a different time period. The fly ashes which are produced from same sources, with one type of chemical composition have different mineralogical structure with another, depends upon coal combustion technique. Subsequently it, affects the hydration properties of fly ashes. The fly ashes, which are encounter in field by engineers in the field, are widely varied in their properties and response to external nature. The physio-chemical behavior controls their nature. In the present time, the geo environmental factors are more complex and engineers are forced to face such situation. Like soil, the fly ashes have also unfavorable situations in field, so fly ashes are also need to check its variation of properties, before its applications in the field. The behavior and composition are so much different that, all of fly ashes are doing not meet all requirement in all conditions. Hence properties characterizations of fly ashes are necessary for, any fly ash consideration for geotechnical applications. Many ways the unfavorable conditions are suit to modify, the fly ash properties for suitable performance in the field. From the following Fig1.2, the results of variation of optimum moisture content (OMC) and maximum dry density (MDD) for different fly ashes collected from the different plant over different time period are varying from 3 days to 2 years.

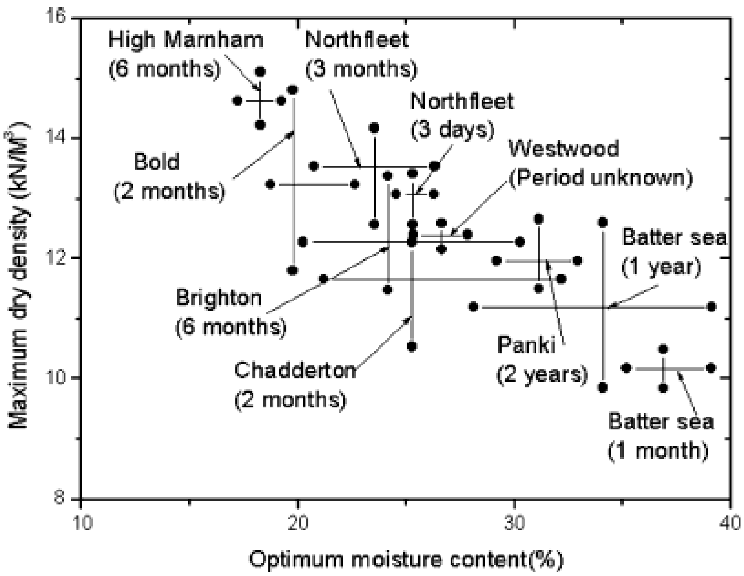


Fig1.2 Variation of OMC with MDD over different time period over different sources Reference[12]

Compared to other fly ashes, the variations in Panki fly ash found to be less. This has implication in terms of quality control specification of dry density and water content in the field compaction of fly ash. There are many factors like gradation, carbon content, iron content, and fineness etc., which control compaction characteristics of fly ashes. Like soils, the fly ashes are also some particulates and heterogeneous matters, so no two fly ashes obtained from different sources are alike. Even though, the fly ashes obtained from same plant with different time are also different in nature.

1.5 Fly Ash Utilization

Utilization of fly ash in particular, can be broadly grouped into three categories.

The **Low Value Utilizations** includes, Road construction, Embankment and dam construction, back filling, Mine filling, Structural fills, Soil stabilization, Ash dykes etc.

The **Medium Value Utilizations** includes Pozzolana cement, Cellular cement, Bricks/Blocks, Grouting, Fly ash concrete, Prefabricated building blocks, Light weight aggregate, Grouting, Soil amendment agents etc.

The **High Value Utilizations** includes Metal recovery, Extraction of magnetite, Acid refractory bricks, Ceramic industry, Floor and wall tiles, Fly ash Paints and distempers etc.

Instead of these, there is large wastage of fly ash material, so large number of technologies developed for well management of fly ashes. This utilization of fly ash increased to 73 MT upto the year 2012. Fly ash has gained acceptance from the year 2010-12. The present production of fly ashes in the country India are about 130 MT per year and expected to increase by 400MT by year 2016-17 by 2nd annual international summit for FLYASH Utilization 2012 scheduled on 17th & 18th January 2013 at NDCC II Convention Centre, NDMC Complex, New Delhi.

Table1.1 Production & Utilization of fly ashes in different country

Ref: Alam and Akhtar , Int Jr of emerging trends in engineering and development , Vol.1 [2] , (2011)

Country	Annual ash production, MT	Ash utilization in %
India	131	56
China	100	45
Germany	40	85
Australia	10	85
France	3	85
Italy	2	100
USA	75	65
UK	15	50
Canada	6	75
Denmark	2	100
Netherland	2	100

From the above Table1.1, the fly ash utilization in India is 56% for the country during the year 2010-12, hence rest of the fly ashes are waste material. Now, it’s necessary to use all of fly ash, considering its adverse effect on environment. Lots of effort has been made to utilize the fly ash upto 100%. For this mission, energy foundation announces 2nd international summit on 2013 for fly ash utilization. The mission is also gathering some knowledge, information about solution for development of suitable utilization of fly ash.

The well planned coal utilization, concentrated on its bulk utilization. This is possible only when, we make geotechnical applications such as back filling, embankment construction, and pavement construction like this. We can utilize more than 60% fly ash for low value applications, if execution is proper. For this a thorough analysis be require for check the physical, chemical and geotechnical properties, for suitability of fly ashes.

CHAPTER 2

Literature Survey

2.1 Introduction

Since 1970's various effort have been made in utilization of fly ash in geotechnical engineering field. This chapter deals with literature on fly ash production and its utilization in real field, types of fly ashes, variation on properties of fly ashes from different sources and the literature based on experiment methodology to check fly ash properties.

From, present scenario, India depend 65-70% production of electricity with coal based power plant, in which the fly ash production in India is, 110 MT/year. So, from Table2.1 now the current ash utilization in India are:

Table2.1 Utilization of fly ash for different purpose Data source: Ministry of Environment & Forests

Mode of Fly Ash Applications	% Utilization
Dykes	35
Cement	30
Land Development	15
Building	15
Others	5

2.2 Classification Of Fly Ash

After Pulverizations, the fuel ash extract from flue gases, by electrostatic precipitator is called fly ash. It is finest particles among Pond ash, Bottom ash and Fly ash. The fly ashes are extracted from, high stack chimney. Fly ash contains non combustible particulate matter, with some of unburned carbon. Fly ashes are generally contains silt size particles. Based on lime reactivity test, fly ashes are classified in four different types, as follows:

- Cementitious fly ash
- Cementitious and pozzolanic fly

- Pozzolanic fly ash
- Non-pozzolanic fly ash

The fly is called cementitious, when it has free lime and negligible reactive silica. A pozzolanic fly ash is one which has reactive silica and negligible free lime content. The cementitious and pozzolanic fly ash contains, both free lime and reactive silica predominantly. Non-pozzolanic fly ash contains neither of free lime nor of reactive silica. The non pozzolanic fly ash do not take part in self cementing or pozzolanic reactions. Main difference is that, cementitious material hardens, when come in contact with water and pozzolanic fly ash hardens only after , get in contact with activated lime with water. The second and third category of fly ashes found widely.

Another way of classification of fly ash is that, class C and class F category of fly ashes, based upon chemical composition. Class C category of fly ashes obtained from burning lignite and sub-bituminous type of coal, which contains more than 10% of calcium oxide. Class F category of fly ashes obtained from, burning bituminous and anthracite type of coal, which contains less than 10% of calcium oxide.

The chemical compositions of any fly ashes, which are categorize into class C or class F fly ashes are as follows in Table2.2:

Table2.2 Chemical requirement of class C and class F fly ashes (data source: ASTM C618-94a)

Particulars		Fly ash	
		Class F	Class C
$SiO_2+Al_2O_3+Fe_2O_3$	:% minimum	70.0	50.0
SO_3	:% maximum	5.0	5.0
MC	:% maximum	3.0	3.0
LOI	:% maximum	6.0	6.0

Many of fly ashes, in India are basically class F fly ash, since majority of coal are bituminous.

2.3 Literature Based On Fly Ash Study

Sherwood and Ryley(1970) studied that, the fraction of lime present in fly ash , behaves the self hardening properties of fly ash, in the form of calcium oxide.

Gray and Lin(1972) studied , the variation of specific gravity of fly ashes and is due to the particle shape & size , gradation and chemical composition.

Mclaren and Digioia(1987) studied that the fly ashes have low values of specific gravity as comparsion to soil, so it can use as backfill material for embankment, weak foundation soil. Since, earth pressure exerted by fly ashes are small.

Martinet al(1990) , stated that fly ash in moist and partial saturate conditions, shows apparent cohesion values, due to capillary rise and it is not to be use as long term stability of fly ash. For shear criteria shear strength is the major one.

Yudbir and Honjo(1991) found that lime content of fly ash behaves as self hardening properties, depends upon availability of free lime & carbon content in the samples.

Wesche(1991) studied that ,the loss of ignition percentage on fly ash , determine the presence of unburnt carbon on fly ash.

Rajasekhar(1995) found that fly ashes are mainly consists of cenosphere and paleosphere .The low values of specific gravity are due to spherical particle present in which the entrapped air bind within it.

Singh(1996) studied that the unconfined compressive strength is a function of free lime content and apparent cohesion.

Singh and Panda(1996), shows that shear strength of a sample of freshly compacted fly ash is a function of and of internal friction angle, which in turn depends upon the maximum dry density of fly ash sample.

N.S Pandian(1998) The low specific gravity ,good draining nature ,ease way of compaction , good frictional properties etc, can easily gain the use of any geotechnical engineering applications.

Pandian and Balasubramonian(1999) The co-efficient of permeability of fly ash depends upon degree of compaction, grain size distribution and pozzolanic activity of fly ashes.

Erdal Cokca(2001) Fly ash consists of hollow spherical cells of silicon, aluminium and iron oxide, so it provides a array of bivalent and trivalent cation like Ca^{+2}, Al^{+3} anf Fe^{+3} in ionized state, which can promotes the disperse clay minerals.

Das and Yudhbir(2005) They said that the lime content, iron content, loss on iginition , morphology and mineralogy structure affects the geotechnical properties of fly ashes.

2.4 Literature Based On Variability Of Fly Ash Properties

Gray and Lin (1972) Many factors are responsible for large variation in values of specific gravity of fly ashes such as gradation, particle shape and size and chemical composition. The shear strength parameters , using triaxial shear test, the fly ash as-compacted state for partially saturated condition is due to apparent cohesion and curing period(for pozzolanic fly ash).

Lambe and Whiteman (1979) For dry sand the angle of repose is approximately equal to angle of shearing resistance in loose state.

Leonards and Bailey (1982) Fly ashes are fine grained substances consisting of mainly silt sized particles of uniform gradation

Hart et al., (1991) The X-ray diffraction study indicates that fly ashes predominantly contain quartz and feldspar minerals.

Ranjan et al., (1998) study that quartz , mullite may be present as crystalline compounds consists of 10-15% by weight of fly ash.

Sridharan et al., (1998) For direct shear box test under as compacted condition, fly ashes exhibits apparent cohesion, due to capillary stresses as a consequence of partial saturation.

Prasad and Bai (1999) studied that due to high reactive silica present in fly ash, fly ash exhibit greater lime reactivity than bottom ash or pond ash.

Sridharan and Prakash (2000) Fly ashes show negative free swell indices due to , low values of specific gravity and due to flocculation and as a consequence of their free lime content.

Sridharan et al., (2001) found that the principal constituents of fly ashes are silica(SiO_2), alumina(Al2O3) and ferric oxide(Fe2O3).Oxides of calcium, magnesium and sodium are also present in fly ashes. If carbon particles do not burn in furnace of boiler, then unburnt carbon particles are also present in fly ashes, and this can be determined from loss on ignition test.He also studied that the pH of fly ashes vary in the range of low value 3 to high value about 12. About 50% of Indian fly ashes are alkaline in nature.

Sridharan et al., (2001) study that the morphology through SEM indicates fly ash contains glassy solid spheres, hollow spheres, sub rounded porous grains, irregular agglomerates and irregular porous grains of unburned carbon(black in colour). If iron particles are present , they can be spotted as angular grains of magnetite (dark gray in colour). The low reactivity of fresh sample indicates low reactive silica or free lime content or high unburned carbon content in fly ash. The particle size distribution and grain characteristics of fly ashes, determine the constitutive behavior and other physical and engineering properties of fly ashes. As fly ashes are predominantly silt size particles, specific surfaces of fly ashes are quite low as compared to kaolinite. The range of specific surface of indian fly ashes are 130-530 m^2/kg

Sridharan and Pandian (2001) Compacted fly ash tested in unsoaked condition , have higher CBR values ,then soaked condition of most of the fine grained soils. Such higher CBR value is due to capillary force, that exist in the partly saturated state.

Das and Kalidas (2002) The specific surfaces of fly ashes , subjected to grain size in ESP hoppers may vary considerably.

Trivedi and Sud (2004) The specific gravity increases, with increase in fineness and finest fly ash has maximum specific gravity. Table shows that, some of variation in specific gravities.

Prakash and Sridharan(2006) If more than 50% of fines (i.e., fraction of size finer than 75μm) belongs to either the coarse silt size category or the medium silt size category or (fine silt+clay) size category , then the ash is represented as MLN or MIN or MHN respectively.

Prakash and Sridharan(2007) The fly ashes exhibit lower γ_{dmax} and higher OMC. This is due to their low specific gravity, poorly graded particles and presence of more cenospheres. The coarser fly ashes higher OMC and lower γ_{dmax} , while finer fly ashes exhibits a lower OMC and higher γ_{dmax}. The coefficient of permeability is a function of grain size distribution, degree of compaction and pozzolanic property of fly ashes. For compacted ashes, k decreases with the degree of compaction increases. Fly ashes falls in the range of k of silts. For partially saturated compacted fly ash , exhibits some UCC strength due to capillary stress induced some apparent cohesion and pozzolanic action.

Fly ash has been classified in two classes class C and class F fly ashes. Class C fly ash is produced from burning lignite and sub-bituminous coal. Class F fly ash is produced from burning bituminous and anthracite coal as per **ASTM C618-94a**.

CHAPTER 3

Materials and Methods

3.1 Introduction

This chapter discuss the materials use and the methods applied for determine chemical, physical and engineering properties of fly ash materials. Large scale utilization of fly ash reduces the problem faced by thermal power plants, which reduce the deforestation and reduce the natural earth material. Assessment of behavior of fly ash is essential, before use it as a construction material. Even, though the adequate support of full scale field test are not available, laboratory test control the adequate support of variables encounter in real engineering practice. The behavior & trend observed in laboratory test experiment, practically realized the understanding of performance of material in structural field and may be use as mathematically relationship to predict the behavior of field structures. The details of material use, sample preparation and experimental procedures have been outline in this chapter.

3.2 Material Used

3.2.1 Fly Ash

The fly ash is light weight coal combustion by product, which result from the combustion of ground or powdered bituminous coal, sub-bituminous coal or lignite coal. Fly ash is generally separated from the exhaust gases by electrostatic precipitator before the flue gases reach the chimneys of coal-fired power plants. Generally this is together with bottom ash removed from the bottom of the furnace is jointly known as coal ash. The fly ash is highly heterogeneous material where particles of similar size may have different chemistry and mineralogy. There is variation of fly ash properties from different sources, from same source but with time and with collection point (Das and Yudhbir, 2005). Fly ash contains some un-burnt carbon and its main constituents are silica, aluminium oxide and ferrous oxide. In dry disposal system, the fly ash collected at the bottom of the mechanical dust collectors and ESPs. From the dry storage silos also fly ashes are collected in closed wagons or moisture proof bags or metallic bins, if the quality of the fly ash is good. The dry fly ash so collected is then transported to the required locations where it is subjected to further processing before its use in many non-geotechnical applications such as cement industry, brick manufacturing and the like. In the present study fly ashes were collected from four different sources of power plants from the hopper. The fly ashes were collected from captive power plant of Mahavir ferro alloy pvt ltd IDC Kalunga, National Thermal Power Corporation Kaniha, Talchir Thermal Power Station Talchir and captive power plant of National Aluminium Company Ltd, Anugul. Before going to test, the samples were screened through 2 mm sieve , to separate out the vegetative and foreign material. To get a clear homogeneity, the samples are mixed thoroughly and get into the oven nearly about 105-110 ^{0}C. The materials are stored in air tight container, for subsequent use.

3.2.2. Lime

Lime produced from mines from different types of lime kiln. It is extracted from stone product by calcinations process at about 1000^{0}C.

Hence the process is $CaCO_3$+heat$\rightarrow$ CaO+CO_2

When quicklime hydrated with water formed slacked lime i.e, CaO+$H_2O$$\rightarrow$$Ca(OH)_2$.

Calcium oxide, CaO was used in this project work, to sieve through 150 μ sieve, which kept in a air tight container for subsequent use.

3.3 Experimental Setup And Procedure

The present study consists of experimental methods for characterization of fly ash. The experimental methods refer to investigation of fly ash in terms of morphological, chemical, physical and geotechnical properties. The thorough understanding of the chemical, physical and geotechnical engineering properties of coal ashes and their engineering behavior, as the property characterization of coal ashes governs their suitability for various geotechnical end uses. The experimental methods in the present study are elaborated as follows:

3.4 Chemical Properties Mineralogy

Chemical properties of fly ashes are mostly influence by the environmental factors composition, which arise their general use as well as engineering properties. Hence, the detail study of chemical properties governs with chemical composition, pH, X-ray diffraction, Lime reactivity etc.

3.4.1 Chemical Composition

Chemical composition suggests the best possible applications of fly ashes. It has seen that, the presence of calcium silicate and aluminium silicate affects the pozzolanic activity of fly ash. Relatively high percentage of carbon decreases the pozzolonic activity. The chemical composition adversely influence the index and engineering properties of fly ash like presence of alumina, silica, iron and unburnt carbon. If more iron content is available, then it gives more specific gravity. Unburned carbon in coal ashes also affects their pozzolanic reactivity, composition and strength characteristics. Pozzolanic characteristics and reactive silica content make the coal ashes different from soils. For knowing the chemical composition, the Energy Dispersive X-ray (EDX) micro analyser fitted with SEM. From the weight percentage of individual element present, the weight percentage of oxides of elements can be calculated.

3.4.2 X-Ray Diffraction

The X-ray diffraction technique gives the idea about the crystalline element present in it, carried out primarily to identify the mineral phases. The process of ash formation controls or retards the morphology and crystal growth of minerals. Even though fly ash is regarded as an amorphous ferro alumino silicate material, the X-ray diffraction spectra of fly ashes indicate that they contain both crystalline and amorphous phases of materials. The samples were dried at 105^0C and mainly taken into powered form for X-ray diffraction analysis. X-ray powder diffraction was initially carried out on the powders for qualitative identification of mineral phases. The sample is analyzed by passing through a Philips diffractometer with a Cu $K\alpha$ radiation source and a single crystal graphite monochromator. An angular range of $10\text{-}60^0$ of 2θ value in 0.1^0 increments was used throughout. The test has been carried out at NIT Rkl (Metallurgical & Materials Engineering Dept).

3.4.3 Scanning Electron Microscope Studies

Scanning electron microscope , study shows that the clear and close view of individual particles of fly ashes , which further signify that fly ashes are finer than bottom ash. Investigations show that the fly ash particles are generally cenospheres and plerospheres leading to low values for specific gravity. The chemical and mineralogical characterization of fly ash is not only beneficial for knowing its composition, but also helps in its classification for its possible utilization as an engineering material. The particle morphology of fly ash is analyzed using Scanning Electron Microscope (SEM).The particle shape is quantified by using image analysis. The SEM used in the present study is JEOL-JSM-6480 LV model.SEM used to scan a finely focused beam of kilovolt energy. An image is formed by scanning electrode ray tube in synchronism with the beam and modulating the brightness of this tube with beam excited signals. The samples are prepared with carbon coating before being putting in the SEM.

3.4.4 pH Of Coal Ashes

If fly ash contains more free lime and alkali, it exhibits more pH value. Since, maximum fly ashes tested in laboratory are alkali in nature. The degree of solubility of the oxides in turn depends upon the pH of the aqueous medium. Direct reading type conforming to pH test conforming to IS 2720 (part 26) – 1987 with glass electrode and a calomal reference electrode or any other suitable electrode can be used. pH values of coal ashes mainly depend upon their alkaline oxide content and free lime content. pH of coal ashes can vary over a wide range from , extremely low of the order of about 3 to a value as high as 12. About 50% of Indian fly ashes are alkaline in nature. The acidic or alkaline characteristics of fly ash can be quantitatively expressed by means of hydrogen ion concentration i.e, $-\log[H^+]= pH$,where H^+ is expressed in moles/litre.

3.4.5 Lime Reactivity

The silicious material reacts with calcium present in fly ash and with moisture forms a cementitious compound. The reaction goes on to form water insoluble calcium silicates and aluminium silicates. This property is called as lime reactivity. Lime reactivity of fly ash depends upon free lime, reactive silica, iron and unburned carbon content. Silica in form of amorphous or as aluminate in crystalline form is called as reactive silica.It is tested under specified conditions, by compressive strength of standard mortar cubes of fly ashes as specify in (IS: 1727, 1967)

3.5 Physical Properties:

The Bulk utilization of fly ash is mainly in areas such as backfill, construction of embankment and backfill. These application needs to check the physical properties of fly ashes.

Basically, physical properties are classifying the fly ashes for engineering purpose and use in engineering field also. The properties discussed are specific gravity, grain size distribution, free swell index and specific surface, geotechnical classification system for fly ashes.

3.5.1 Specific Gravity

For all normal calculation relative density, void ratio, hydrometer analysis, specific gravity are important tool for geotechnical applications. In general, the specific gravity of coal ashes lies around 2.0 but can vary to a large extent (1.6 to 3.1). Because of the generally low value for the specific gravity of coal ash compared to soils, ash fills tend to result in low dry densities. The low values of specific gravity is a advantage for use fly ash as a backfill material, which exert low pressure in earth retaining wall or any foundation structure. The specific gravity of fly ash can be done accordance with IS: 2720(part III/Sec.I) 1980.

3.5.2 Grain Size Distribution

The grain size distribution curve gives the idea about fine or coarse grain type of particle present, according to that it classify the fly ashes. Most sizes of particles present in fly ashes are silt size particles. Before going for hydrometer analysis, fly ash to need for wet sieve analysis through 75µ sieve size. Wet Sieve analysis was conducted for coarser particles greater than 75µ and hydrometer analysis was conducted for finer particles less than 75µ as per IS: 2720 (part IV)-1985. Coefficient of uniformity (C_u) and coefficient of curvature (C_c) for fly ash was also to be found out. As per specification, the hydrometer analysis shall be done using the dispersion agent sodium hexameta phosphate.

3.5.3 Free Swell Index (FSI)

Free swell is the increase in volume of a soil, without any external constraints, on submergence in water. The possibility of damage to structures due to swelling of expansive clays need be identified, by an investigation of those soils likely to possess undesirable expansion characteristics. The level of the soil in the kerosene graduated cylinder shall be read as the original volume of the soil samples, kerosene being a non-polar liquid does not cause swelling of the soil. The level of the soil in the distilled water cylinder shall be read as the free swell level. The free swell index of the soil shall be calculated as follows:

Free swell index, percent =($V_d - V_{k)}/V_k$ *100

Where

V_d= the volume of soil specimen read from the graduated cylinder containing distilled water

V_k = the volume of soil specimen read from the graduated cylinder containing kerosene.

This part IS: 2720 (Part XL)-1977 deals with the method of test for the determination of free swell index of soils.

3.5.4 Specific Surface

This theory is based on, Brunauer Emmett Teller, (BET) which explain the physical attraction of gas molecules on its solid surfaces, which is based on important analysis for measurement for specific surface area of material. The concept of this theory is the extension of Langmuir theory, which says that, gases molecule monolayer adsorption to multilayer adsorption. This hypotheses is based on (i) The gas molecules physically adsorbed the solid surfaces infinite no of process. (ii) There is no interaction between each layer of adsorption. (iii) After, that Langmuir theory can be applied to each layer. According to IS: 11578-1986 determination of specific surface of powder or powder porous material, quantity of nitrogen which completely covers the surface of solid area is calculated independently. Number of such gas molecule, multiplied with area of each molecule of contact surface gives the total area per unit material.

3.5.5 Geotechnical Classification System For Coal Ashes

As per USCS, soils are broadly classified into coarse grained and fine grained, depending upon percentage passing through 75 micron sieve. The fly ashes are also classified in geotechnical engineering view point based on particle size distribution and gradation, using geotechnical engineering classification system (Prakash and Sridharan, 2006). Further classification is based on hydrometer analysis by IS:2720(Part4)-1985 for check the plasticity character of fly ashes. Gradation of fly ashes is similar to USCS classification system, except it has no plasticity chart. Hence L, I and H are used to indicate the Coarse silt size fraction (20 micron< particle size < 75 micron), Medium silt size fraction(7.5 micron< particle size < 20 micron) and fine silt+clay size fraction respectively.

If more than 50% of fines (i.e., fraction of size finer than 75μm) belongs to either the coarse silt size category or the medium silt size category or (fine silt+clay) size category, then the ash is represented as MLN or MIN or MHN respectively.

Table3.1 Fly ash classification system (data source Prakash and Sridharan 2007)

<table>
<tr>
<td rowspan="3">Fine grained fly ashes
(More than half of the material is smaller than 0.075 mm sieve)</td>
<td rowspan="3">Hydrometer analysis on fraction smaller than 0.075 mm size</td>
<td>More than 50% of fines is in the particle size range ($20\mu m < \text{particle size} < 75\mu m$)</td>
<td>MLN</td>
<td>Non-Plastic inorganic coarse silt sized fractions</td>
<td rowspan="3">Use of dual symbols:
If more than 50% of fines is in the range $7.5\mu m < \text{particle size} < 75\mu m$, which is also more than the percentage of combined medium silt and (fine silt+clay) size fractions, then use MLN-MIN

If more than 50% of fines is in the range particle size $< 20\mu m$,which is also more than the percentage of combined coarse silt and medium silt size fractions,then use MIN-MHN</td>
</tr>
<tr>
<td>More than 50% of fines is in the particle size range ($7.5\mu m < \text{particle size} < 20\mu m$)</td>
<td>MIN</td>
<td>Non-Plastic inorganic medium silt sized fractions</td>
</tr>
<tr>
<td>More than 50% of fines is in the particle size range , particle size$<7.5\mu m$</td>
<td>MHN</td>
<td>Non-Plastic inorganic(fine silt+clay)sized fraction</td>
</tr>
</table>

The typical chart Table3.1 have shown the classification of fly ashes passing through more than half of the material through 0.075 mm sieve size.

3.6 Engineering Properties

The bulk utilization of coal ashes in geotechnical applications such as construction of embankments, back filling, construction of roads and the like. A clear idea of all engineering properties of fly ashes is essential for any planning and execution of civil engineering project.

3.6.1 Compaction Characteristics

From compaction curve, the maximum value of dry density is important parameters for strength, permeability and compressibility calculation. The engineering properties improve only due to densification of fly ash. The maximum unit weight of material depends upon the method of energy applications, plasticity characteristics, grain size variation, and moisture content at compaction state. The variation of dry density with moisture content is less as compared to well graded soil. For wide variation of change in specific gravity of fly ashes with those of soils, it needs to compare the normalized values of moisture content and normalized values of dry unit weight, of fly ash with those of soils

Normalized dry unit weight= $\gamma_{dn}=\gamma_{dm}[G_{std}/G_m]$

Normalized water content = $w_n=w_m[G_m/G_{std}]$

With knowledge of the water density relation as determined by this test, better control of the field compaction of soil fill is possible. This standard IS: 2720 (Part VII) – 1980 lays down the method for the determination of the relation between the water content and the dry density of soils using light compaction, in which a rammer of 2.6 kg mass with fall of 310 mm is used to compact the soil in the mould in three layers, each layer being subjected to 25 blows of the rammer.

3.6.2 Permeability Characteristics

The use of this test is to determine the permeability (hydraulic Conductivity) of fly ash by the variable head permeability test. The coefficient of permeability (or hydraulic conductivity) refers to the ease with which water can flow through a soil. The coefficient of permeability of fly ashes falls in the range of 'k' of silts. This property is essential for the calculation of seepage through earth dams or under sheet pile walls, the calculation of the seepage rate from waste storage facilities (landfills, ponds, etc.). The Permeability of fly ash depends upon grain size, degree of compaction, pozzolanic activity etc. The codal provision follows for this experiment is IS: 2720 (Part 17) – 1986 . Calculate the permeability, using the following equation:

$K=[(a*L)* \log_e(h_1/h_2)]/(A*t)$

The variable head test is preferred, because of permeability of most of fly ashes falls in the range of 'k' of silts. The particles are able to densely pack during compaction, resulting in comparatively low values of permeability and minimum seepage of water through fly ash embankment.

3.6.3 Unconfined Compressive Strength

Unconfined compressive test can exist for clays by virtue of their cohesion component of the shear strength, which arises due to capillary stress and also it is the strength obtained by testing the material specimen of standard diameter i.e., L/D=2 and height having a known dry density and water content under a gradually increasing axial compressive load. This is used to calculate the differential settlement calculation of fly ash embedded structure. The UCS test were performed according to IS: 2720 (Part X)-1991.

3.6.4 Lime Fixation

Due to low shear strength of fly ash various studies have been made to stabilize using lime. Variation of the strength of fly ash due to the addition of lime is controlled by following mechanism, formation of cementitious compounds due to pozzolanic reactions, which increases the strength. Most of the fly ashes are characterized by the low free lime content, in spite of having appreciable reactive silica in them. However, the most important point is the finding of the optimum lime percentage. In the present study, the optimum amount of lime, known as lime fixation point, it is defined in terms of the lime content with maximum unconfined compressive strength (UCS), beyond which the UCS either remains constant or decreases. The UCS strength is performed for lime fixation. The UCS test were performed according to IS: 2720 (Part X)-1991.

3.6.5 Shear Strength From Direct Shear Box Test

The purpose of this test was to calculate cohesion (c_u) and angle of friction (ϕ_u) of fly ash. As fly ash is non-cohesive at un-disturbed state, sample was made at its OMC. Fly ash specimen was made at OMC, and then it is prepared by pushing a cutting square size of plate. The lower part of shear box which bear against the load jack was set along the upper part of the box to bear against the proving ring. Dial of the proving ring was set to zero. The shear parameters samples at their corresponding MDD and OMC were determined according to IS: 2720 (Part XIII) 1986.These samples were of size 60mm×60mm×25mm.

3.6.6 Shear Strength From Triaxial Shear Tests

The useful laboratory test conducted to determine the shear strength of soils is the triaxial shear test. Shear tests, namely unconsolidated undrained shear test, consolidated undrained shear test with or without pore pressure and consolidated drained shear test, can be conducted with ease using the standard triaxial shear test set up. For fly ashes, the effective friction angle is relatively high. For pozzolanic fly ash, another factor that affects the shear strength parameters is the curing period. For immediate fly ash testing, the shear parameters depends upon apparent cohesion, which is due to capillary stress arise. Upto this part the undrained shear strength parameters of typical fly ashes compacted to their γ_{dmax} has been carried out according to IS 2720 (Part 11) : 1993

3.6.7 California Bearing Ratio (CBR)

In geotechnical engineering practice, the ratio of the force per unit area required to penetrate a specimen of soil with a circular plunger of standard size at a standard rate to that required for the corresponding penetration of a standard material is known as California Bearing Ratio (CBR). IS: 2720-Part 16(1979) specifies the diameter of the plunger as 50 mm and the rate of penetration as 1.25 mm/minute. For low lying area drainage is poor, so that submergence of road occurs, then soaked CBR values are useful.

3.6.8 Dispersiveness

The ability of any particulate matter such as soils and coal ashes to get dispersed in water and washed away is known as its dispersiveness. The non-plastic nature of the material contributes to dispersiveness. Non-dispersive materials are best suited for bulky structures like embankment, dyke and all kinds of water retaining structures. The laboratory test, double hydrometer test has been performed for dispersiveness. According to this method:

Table3.2 classification of dispersive soils based on double hydrameter test (data source Prakash and Sridharan 2007)

Degrees of Dispersion: %	Classification
<35	Non-dispersive
35-50	Moderately dispersive
50-75	Highly dispersive
>75	Extremely dispersive

In double hydrometer test, based on hydrometer analysis IS:2720(Part4)-1985 the dispersion ratio is defined as the ratio of the percentage finer than 0.005mm diameter measured without any dispersion agents in a hydrometer test to that measured with dispersion agents, which is expressed in percentage. The percentage of dispersion is an indicator of the ability of soils to erode due to their dispersiveness as shown in Table3.2.

3.6.9 Angle of Repose

The angle of repose is the steepest angle of the slope relative to the horizontal plane when material on the slope face is on the verge of sliding. In general it refers to the maximum angle at which an object can rest on an inclined plane without sliding down. The internal angle between the inclined surface of the material and the horizontal surface is known as the angle of repose and is depends mainly upon to the density, surface area and shape of the particles and the coefficient of friction of the material. The angle is in the range of 0^o to 90^o.The dry fly ash is poured into a cylindrical pipe on a level surface and made it full. Using the ruler top of the surface of fly ash leveled and then cylindrical mould was lifted up. The fly ash mound was placed like a conical shape. The height of the tip of the conical shaped fly ash and the diameter of the spread is measured in terms of height and radius of spread.

CHAPTER 4

Result & Discussion

4.1 Introduction

The following test to characterize the chemical properties of fly ashes has been elaborated as follows. The following tests have been conducted to characterize the sample of fly ash which has been collected from kalunga, NTPC, TTPS and NALCO thermal power plant.

4.2 Chemical Properties

4.2.1 Chemical Composition

From, the present study Table4.1 it shows, that the alumina contain is less than, that of silicon dioxide and calcium oxide contain is less than 10%. Hence, these are the type of class F fly ash. The formation of calcium silicate and aluminium silicate is more in case of NALCO fly ash, which accelerates the lime reactivity process. More iron content in Kalunga fly ash leads to other fly ashes, cause more compressive strength than others.

Table4.1 Chemical composition of fly ashes of present study and some of Indian fly ashes
***(data source Prakash and Sridharan 2007)**

SOURCE	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	LOI	MC
TTPS	40.01	26.82	14.09	4.4	4.74	4.81	3.95	0.63	0.55
Kalunga	29.49	19.46	26.82	3.26	6.59	5.46	-	7.68	1.24
NTPC	37.06	29.02	13.97	4.24	5.23	4.99	4.31	0.70	0.48
NALCO	41.65	22.38	15.04	4.76	4.75	5.82	4.72	0.50	0.38

Source	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	LOI	MC
Neyveli*	38.78	44.24	4.13	0.02	7.87	0.05	0.44	3.47	1.05
Ghaziabad*	53.22	38.14	3.44	0.24	1.01	0.67	0.14	3.04	0.10
Badarpur*	58.45	32.38	4.71	0.23	0.63	0.61	0.23	2.71	0.05
Rihand*	57.94	34.28	5.86	0.40	0.20	0.51	0.30	0.51	-
Raebareli*	60.57	31.10	4.27	0.41	0.91	0.71	0.20	-	1.83

The loss on ignition of Kalunga fly ash is more than other fly ashes. With respect to present study, there is large variation in weight percentage, studied by sridharan(2007). The quartz and mullite percentage are less as compared to previous study, while the oxides of magnesium, potassium and sodium are more for present study. The iron percentage is also more for the present study specially to Kalunga fly ash.

4.2.2 X-Ray Diffraction Spectra

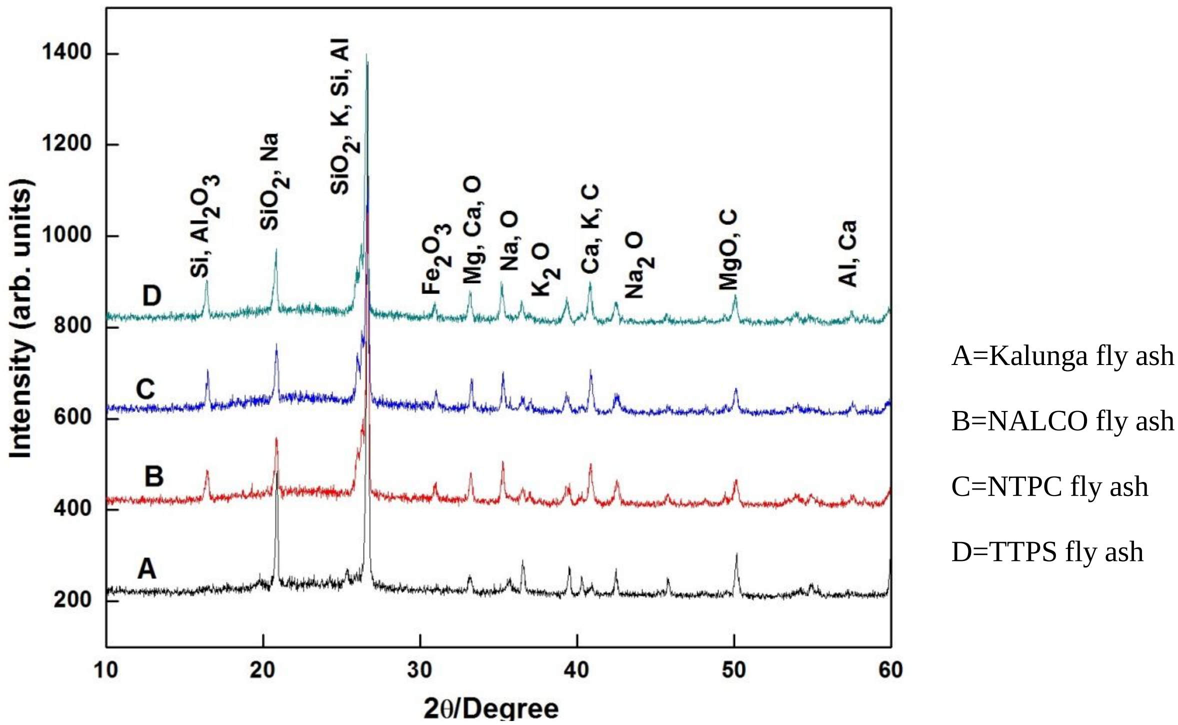


Fig4.1 X-ray diffraction spectra of fly ashes, present study

The XRD spectra Fig4.1 of four fly ashes named as A (Kalunga fly ash), B (NALCO fly ash), C (NTPC fly ash) and D (TTPS fly ash) are follows. In all cases approximately, same number of peaks are shown with little bit different amount of peaks. The maximum no of peaks in crystalline nature is find out for quartz and mullite. Instead of these calcium and hematite are also present in crystalline state. The fly ash contains both amorphous and crystalline phases of minerals. Besides major elements, it also contains oxides of magnesium, potassium or sodium with little amount. If the fly ashes contain presence of unburnt carbon, there will be loss on ignition.

4.2.3 Morphology

The morphological study through SEM indicates that, the NALCO fly ash Fig4.2 contains cenospheres with small agglomerates, while that of TTPS fly ash Fig4.3 contain cenospheres without agglomerates and contains single cells.

In both the cases, fly ash contains glassy solid spheres. In case of NTPC fly ash, Fig4.4 with addition cenospheres, some hollow spheres called as plerospheres are also present with maximum of single grained cells.

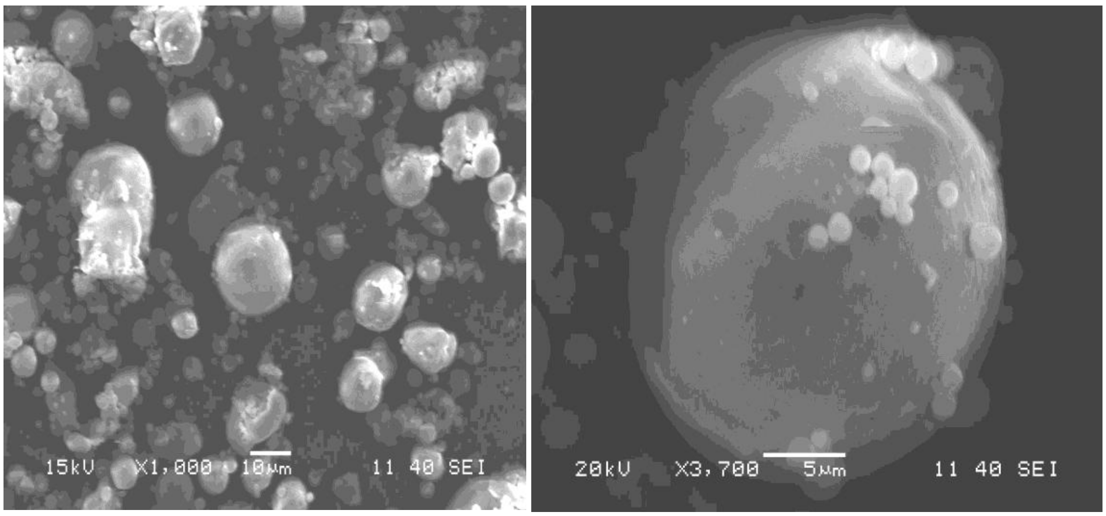


Fig4.2 Surface morphology of NALCO fly ash sample

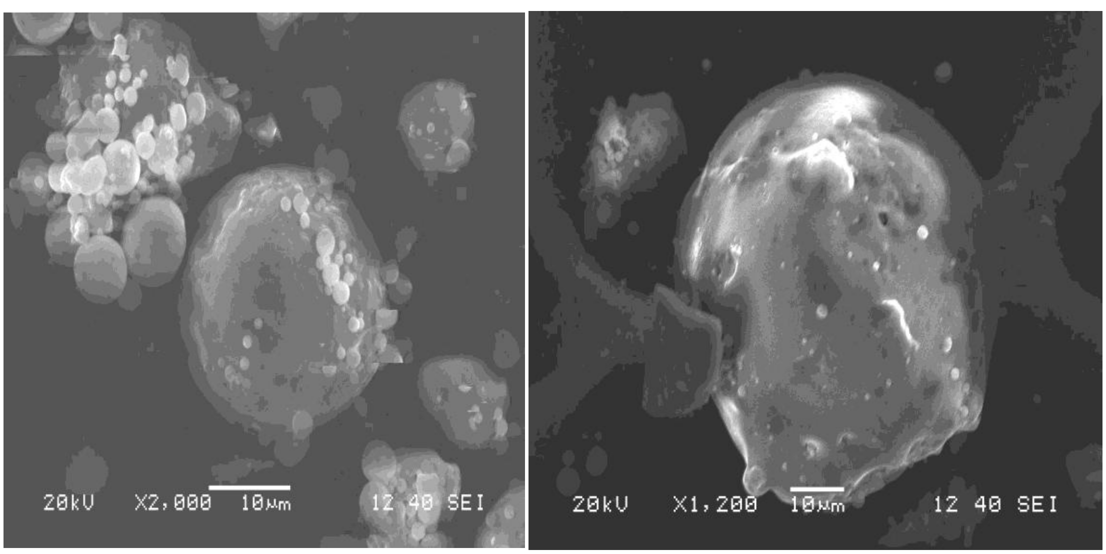


Fig4.3 Surface morphology of TTPS fly ash sample

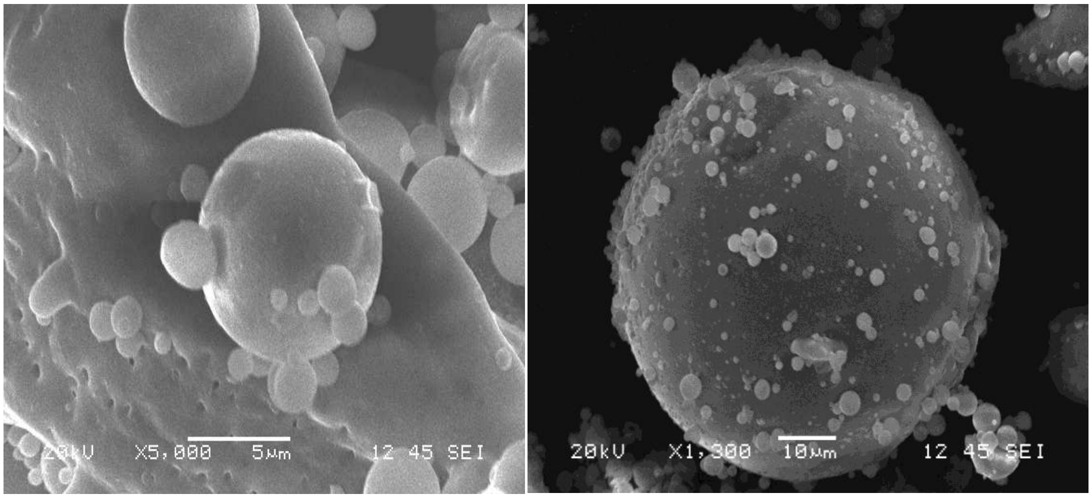


Fig4.4 Surface morphology of NTPC fly ash sample

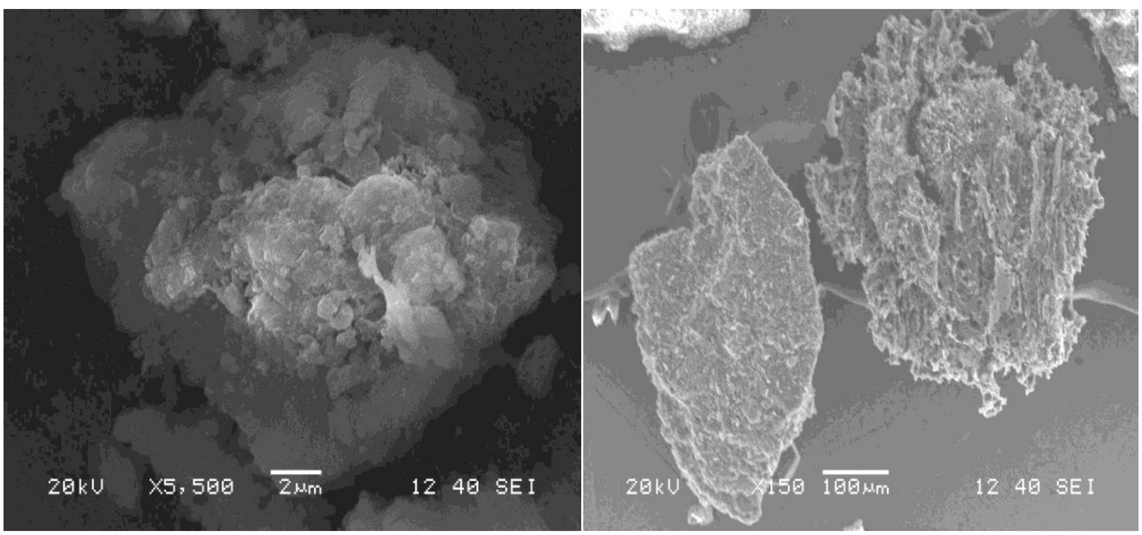


Fig4.5 Surface morphology of KALUNGA fly ash sample

In case of kalunga fly ash Fig4.5 which shows that, it is different from other fly ashes from the surface morphology. It indicates the presence of sub rounded porous grains, irregular agglomerates and irregular porous grains of unburned carbon. The kalunga fly ash looks like spotted as opaque spheres and angular grains, which indicates the presence of magnetite, which is dark gray in color.

4.2.4 pH of Fly Ashes

Table4.2 pH values of fly ashes for present study and some of Indian fly ashes (*data source Prakash and Sridharan 2007)

	Present study				Sridharan (2007)				
Source	Kalunga	NTPC	TTPS	NALCO	**Raebareli***	**Korba***	**Vijayawada***	**Badarpur***	**Ghaziabad***
pH	7.50	7.30	6.00	6.61	7.36	5.13	7.61	6.07	5.52

It shows that from Table4.2, approximately 50% of Indian fly ashes are alkaline and other 50% are acidic in nature. It depends upon the presence of alkaline oxide content and free lime available. As more percentage of CaO available with Kalunga and NTPC fly ash, it shows alkaline in nature.

4.2.5 Lime Reactivity

The lime reactivity of fly ash primarily depends on presence of reactive silica and formation of aluminium silicate and calcium silicate gel. For the present study, it shows that there is more values of lime reactivity for TTPS and NALCO fly ash. This is may be due to presence of more reactive silica present in TTPS and NALCO fly ash, which leads to further formation of aluminium and calcium silicate gel. The present result also, very much match with the experimental result by Sridharan(2007)

Table4.3 Lime reactivity of fly ashes for present study and some of Indian fly ashes (*data source Prakash and Sridharan 2007)

	Present study				Sridharan (2007)				
Source	Kalunga	NTPC	TTPS	NALCO	**Raebareli***	**Korba***	**Neyveli***	**Vindayanagar***	**Ghaziabad***
Lime reactivity: kPa	2786	3120	3276	3306	3060	2558	2143	3580	3269

As per present study, Table4.3 the lime reactivity of Indian fly ashes are also lies within same range. Hence, the decreasing order of Lime reactivity is NALCO, TTPS, NTPC and Kalunga fly ashes respectively.

4.3 Physical Properties

4.3.1 Specific Gravity

The low values of specific gravity of fly ashes can be mainly attributed to the presence of more number of cenospheres present. Practically, for Indian fly ashes the range of specific gravity lies between 1.66-2.55. The following Table4.4 of present study shows that, the values of specific gravity with respect to distilled water and with kerosene.

Table4.4 Specific gravity of fly ashes with water and kerosene as pore medium, present study

Source	Specific gravity (water as pore medium)	Specific gravity (Kerosene as pore medium)	Range (data source:Prakash and Sridharan 2007)
Kalunga	2.41	2.67	1.66-2.55
NTPC	2.04	2.31	
TTPS	2.13	2.58	
NALCO	2.21	2.49	

The increase in specific gravity value with respect to kerosene with that of distilled water is due to easy expulsion of air from the voids of spherical grain particles. From the study , it also shows that there is more value of specific gravity of Kalunga fly ash and it is due to the presence of more iron particles for Kalunga fly ash, from the chemical composition chart. Table4.5 shows the range of specific gravity values of Indian fly ashes.

Table4.5 Specific gravity of some of Indian fly ash with water as pore medium
(*data source Prakash and Sridharan 2007)

Source	Specific gravity (water as pore medium)
Korba*	2.04-2.10
Vijayawada*	2.03-2.11
Ghaziabad*	2.12-2.13
Ramagundam*	1.98-2.23
Neyveli*	2.01-2.55

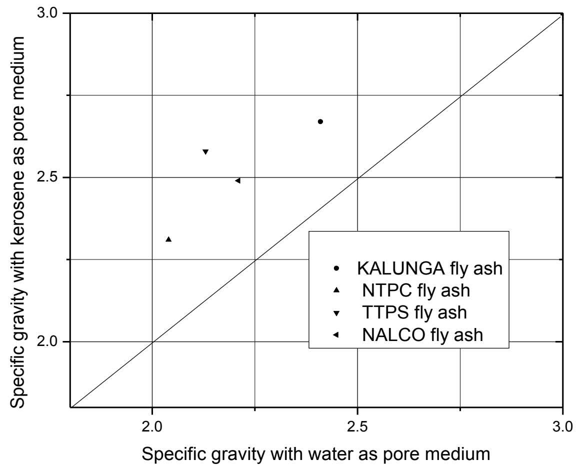


Fig4.6 Vaiation of SG of fly ashes wth water and kerosene as pore medium, present study

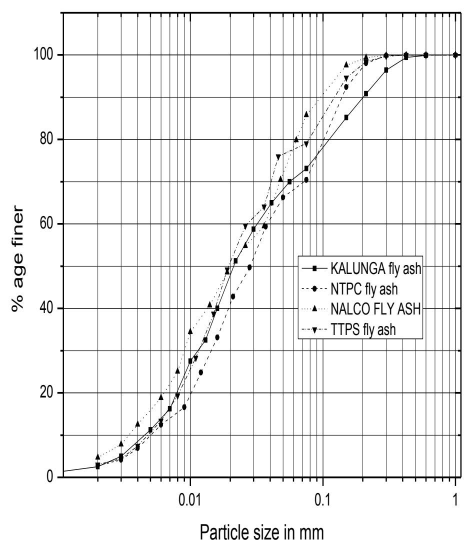
From the equality curve, Fig4.6 it shows that if any non-polar liquid like kerosene is used as the pore medium instead of water, the removal of air is more effective and higher specific gravity values are obtained. The ranges of Indian fly ashes, as per experimental study by Sridharan(2001) are also lies within the values in between 1.66-2.55

4.3.2 Grain Size Distribution

Table4.6 Grain size distribution of fly ashes for present study & some of Indian fly ashes (data source Prakash and Sridharan(2007)

Source	Clay size fraction: %	Silt size fraction: %	Sand size fraction: %	C_u	C_c
Kalunga	2.50	71.94	25.56	7.67	1.04
NTPC	2.98	68.67	28.35	9.63	0.61
TTPS	2.76	74.72	22.52	6.83	0.88
NALCO	3.70	79.63	16.67	5.53	1.08
Raebareli*	2.0	70.0	28.0	5.88	0.75
Korba*	1.0	71.0	28.0	6.00	1.14
Vijayawada*	4.5	70.5	25.0	5.70	0.61
Kahalgoan*	6.0	72.0	22.0	4.00	1.50
Rihand*	14.7	78.2	07.0	4.30	1.70

From the grain size distribution Table4.6 fly ashes are fine grained substances, consisting of mainly silt size particles with uniform gradation. From the Table it shows that, fly ash becomes finer if C_u reduces. The grain size distribution of fly ash have same resemblance with that of grain size distribution of fly ashes studied by Sridharan(2007).



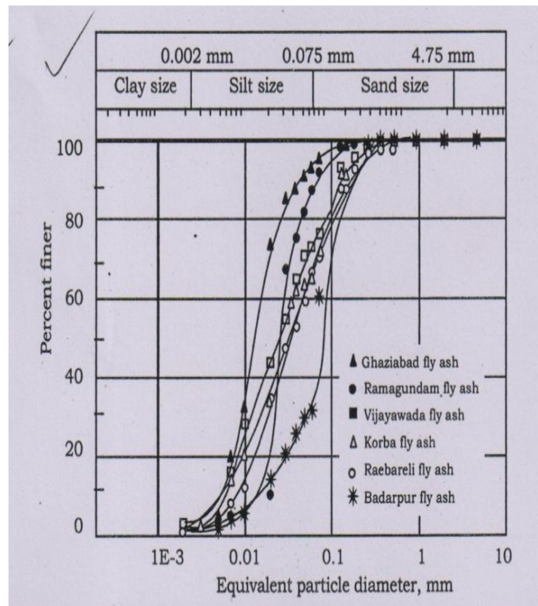


Fig. 3.5. Grain size distribution of typical Indian fly ashes (*data source*: Sridharan *et al.*, 2001e)

Fig 4.7 Grain size distribution of fly ashes for present study

(data source Prakash and Sridharan 2007)

The Fig4.7 shows the grain size distribution curve for fly ashes for present study, which shows similar nature with gradation of Indian fly ashes. Particle size finess, primarily depends upon the no of hopper from which sample collected and according to which grain size gradation changes.

4.3.3 Free Swell Index

Fly ashes exhibits negative free swell indices, it is due to presence of clay particles present in flocculated structure. More the clay particles, more is flocculation and more is the swelling. Hence the swelling, in case of kerosene is more, than that of distilled water. It is due to, more or easy expulsion of air from the voids, as kerosene is a polar liquid. If more swelling in kerosene, than that of water, fly ash exhibits negative free swell ratio.

Table4.7 Free swell ratio of fly ashes for present study and some of Indian fly ashes (data source Prakash and Sridharan 2007)

Source	Free swell index (%)	Remarks
NTPC	-31.34	Due to flocculation
NALCO	-35.53	
Kalunga	-25.00	
TTPS	-30.88	
Raebareli*	-30.10	
Vijayawada*	-34.40	
Badarpur*	-14.30	
Ghaziabad*	-35.00	
Kahalgoan*	-30.80	

From the Table4.7 the present experimental study of fly ashes, resemblances with the experimental investigation by Sridharan (2007)

4.3.4 Specific Surface

As the fly ashes primarily contain silt size particles, there specific surface area is quite low as compared to kaolinite which is coarsest clay mineral. The specific surface area of fly ash is influenced by gradation of fly ash particles. If more than 50% of fines are silty, then it depends upon silt size particles present with it. Primarily, it also depends upon ESP hoppers from which fly ash are collected. If more no of hoppers are present, finer the fly ash particles.

Table4.8 Specific surface area of fly ashes for present study

Source	**Specific surface: m2/kg**
Kalunga	297.3
TTPS	138.5
NALCO	192.1
NTPC	106.5

If more is the specific gravity value, finer the ash particles and more is the specific surface area. Range of specific surface of Indian fly ashes (data source: Sridharan et al., 2001e) are 130-530 m^2/kg. Present study Table4.8 also lies between the specified ranges of Indian fly ashes. The more value of specific surface for Kalunga fly ash is due to presence of more pore spaces available with it.

4.3.5 Geotechnical Classification System For Fly Ash

The fly ashes are satisfactorily classified based upon particle size distribution and gradation characteristics. The present study shows that, there is more percentage of coarse silt size fractions among all others. But, from the experimental investigation by Sridharan (2007), it shows that there is all most equal proportion of sand size and coarse silt size fraction. However, from present study and by Sridharan (2007) Table4.9 study all sources of fly ash particles are categorize under MLN-MIN.

Table4.9 Fly ash classification system of fly ashes and Indian fly ashes (data source *Prakash and Sridharan 2007)

		Particle size distribution: %			**Distribution of fines as a percentage of total fraction passing 75µm size**			**Classification**
Source	**G**	**Clay size**	**Silt size**	**Sand size**	**Fine silt**	**Medium silt**	**Coarse silt**	
Kalunga	2.41	2.50	71.94	25.56	6.29	9.63	56.02	MLN-MIN
NTPC	2.04	2.98	68.67	28.35	5.52	11.56	51.59	MLN-MIN
TTPS	2.13	2.76	74.72	22.52	5.05	8.19	61.48	MLN-MIN
NALCO	2.21	3.70	79.63	16.67	4.73	5.91	68.98	MLN-MIN
		Particle size distribution: %			**Distribution of fines as a percentage of total fraction passing 75µm size**			**Classification**
Source	**G**	**Clay size**	**Silt size**	**Sand size**	**Fine silt**	**Medium silt**	**Coarse silt**	
Raebareli*	2.05	2.00	70.00	28.00	3.9	18.6	27.3	MLN-MIN
Korba*	1.98	1.00	71.00	28.00	9.1	14.5	27.3	MLN-MIN
Vijayawada*	1.95	4.50	70.50	25.00	8.9	19.8	23.0	MLN-MIN
Kahalgoan*	2.21	6.00	72.00	22.00	4.8	23.0	30.0	MLN-MIN
Neyveli*	2.55	9.50	63.90	26.60	5.5	34.5	12.0	MLN-MIN

4.4 Engineering Properties

4.4.1 Compaction Characteristics

From the Fig4.8 shows that compaction curves of fly ashes are relatively flatter due to lower specific gravity, uniformly graded particles, presence of more cenospheres which are dominating factors controlling the compaction behavior of fly ashes. Since, the actual compaction curve of fly ashes not possible to compare with those of soils, it is essential to replot the actual value with normalized values.

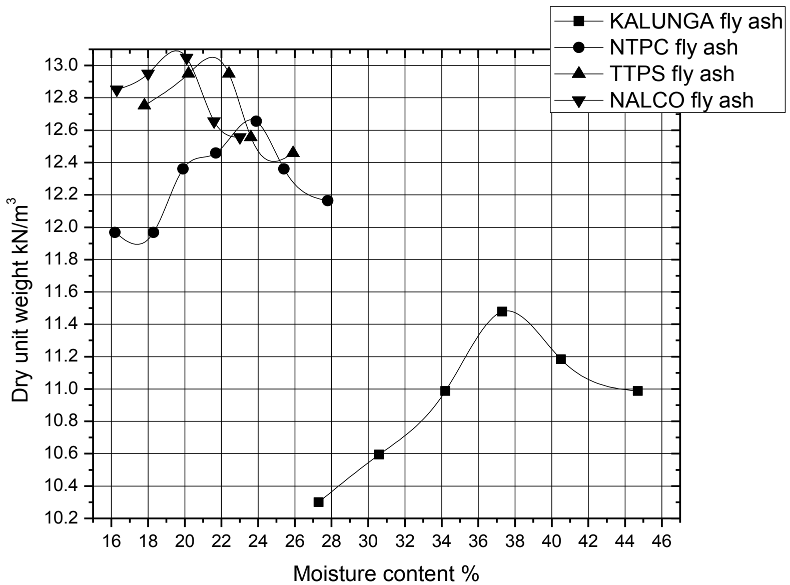


Fig4.8 Compaction curves of fly ashes, present study

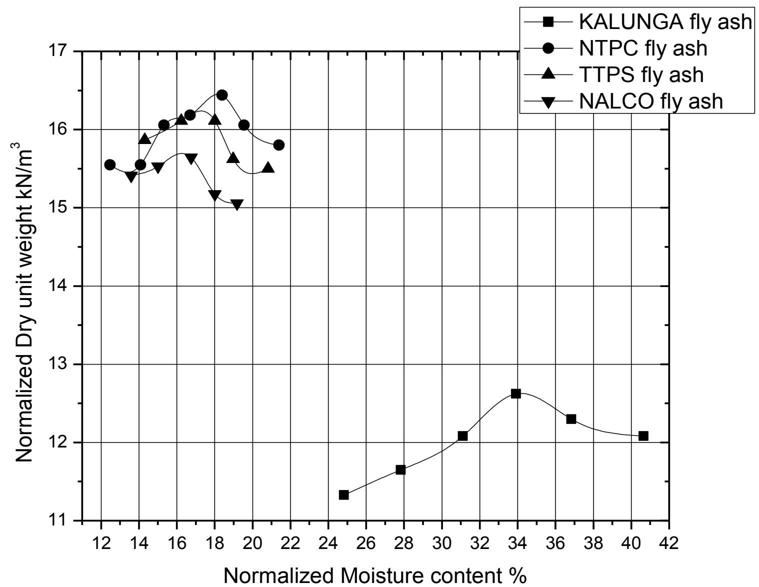


Fig4.9 Normalized compaction curves of fly ashes, present study

The second Fig4.9 is the normalized value of the compaction curve, which facilitates the comparison between compaction characteristics of fly ashes with that of soils. From the present study, the fly ashes are relatively flatter indicating the water insensitive (i.e., low γ_{dmax} and more OMC) and this is due to increased resistance offered by pozzolanic reaction. More void spaces and pore spaces are present in Kalunga fly ash, for which water content is more and giving low value of dry density as comparison to other fly ashes. In general for fly ashes for compactive effort, if ϕ_u value is more, it gives more γ_d value. Further it showed that, OMC is directly and MDD is inversely proportional to LOI. Compared to soil with organic content fly ash exhibit lower γ_{dmax} and higher OMC due to presence of hollow and solid spheres. The following Table4.10 shows the MDD and OMC values of experimental result and some of Indian fly ashes.

Table4.10 Compaction characteristics of fly ashes for present study and some Indian fly ashes *(data source Prakash and Sridharan 2007)

sources	Maximum dry density(MDD) in kn/m^3	Optimum moisture content(OMC) in %	Normalized Maximum dry density(MDD) in kn/m^3	Normalized Optimum moisture content(OMC) in %	Indian fly ashes range
NTPC	12.65	23.9	16.44	18.40	OMC:% 17.9-62.3 γ_d:kN/m^{3}8.9-13.8
NALCO	13.05	20.1	15.64	16.76	
Kalunga	11.48	37.3	12.62	33.92	
TTPS	12.95	22.4	16.11	18.00	
Badarpurl*	11.0	36.9	13.8	29.5	
Ramagundam*	13.8	24.2	16.4	20.4	
Ghaziabad*	12.2	33.2	15.2	26.7	

From the experimental study by Sridharan (2007), the present studies are more correlates. The present study of MDD and OMC lies in the range between the values of Indian fly ashes.

4.4.2 Permeability Characteristics

The self cementing and pozzolanic fly ashes tend to have low permeability than the non pozzolanic fly ashes, due to the formation of pozzolanic compounds that reduce the permeability appreciably with time in the field. The low values of permeability of fly ashes can be considered as additives in the construction of seepage cutoffs like impervious blankets and cores in earth water retaining structures and also lessen the probability of ground water pollution. The permeability values of Table4.11 present study and some of Indian fly ashes are as shown:

Table4.11 Permeability values of fly ashes, present study and Indian fly ashes data source (data source Prakash and Sridharan 2007)

Source	Coefficient of permeability (-*10^-3): mm/s
NTPC	0.393
Kalunga	0.440
NALCO	0.360
TTPS	0.386
Vijayawada*	0.340
Ghaziabad*	0.190
Neyveli*	0.320
Korba*	0.919

From the present study, we can say that if more void ratio or more pore spaces are present it leads to more permeable. More γd value, fly ash exhibits less permeable. Less pozzolanic effect contributes to, more permeability. The table shows that, the permeable values of some of Indian fly ashes, which are approximately close to experimental result. The co-efficient of permeability is defined as the velocity of flow (v) through the porous material per unit hydraulic gradient (i).

4.4.3 Unconfined Compressive Strength

4.4.3.1 Lime Fixation Curve

For the present study all are categorize with low calcium fly ash i.e, class F fly ash. Fig4.10 shows the variation of UCS value with lime content of fly ashes for the present study and it can be seen that UCS value increase with lime content upto lime fixation point .

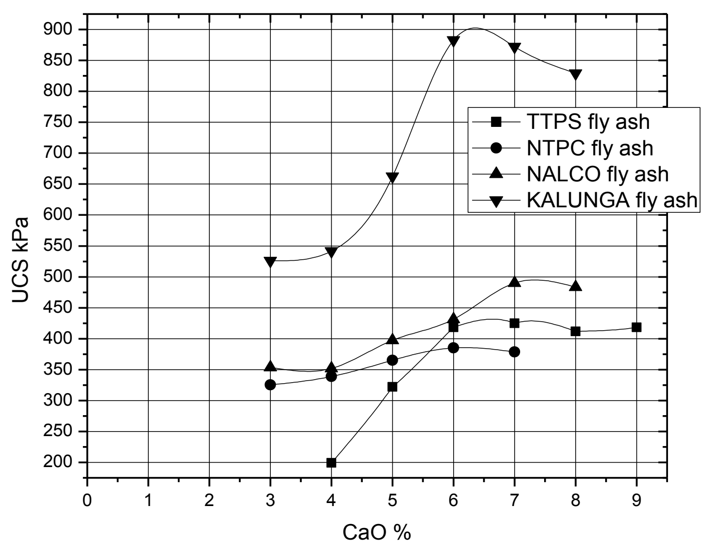


Fig4.10 Effect of lime addition on UCS strength of fly ashes

With additional increase in lime the UCS value appreciable constant for all the fly ashes. Lime fixation point depends upon lime reactivity. Since, availability of reactive silica is restricted for Kalunga and NTPC fly ash; it shows low values of lime fixation i.e., both are 6% respectively. But, the lime reactivity of NALCO and TTPS fly ash has appreciable more than Kalunga and NTPC fly ash, hence more lime i.e, 7% require for lime fixation for both the fly ashes. If present of reactive silica is unavailable, addition of any amount of lime will not effective.

4.4.3.2 Variation Of UCS Value With MC

For the present study with respect to MC, the UCS values of fly ash samples were tested. For the optimization result the starting water content was first water content attained from the standard proctor compaction test. The unconfined compressive strengths of specimens were determined from strain-stress curves plots for different water content for all the fly ashes. Partly saturated compacted fly ash exhibits some unconfined compressive strength when tested in an unsoaked condition. This can be attributed to the capillary stresses and pozzolanic action, induced shear strength or apparent cohesion.

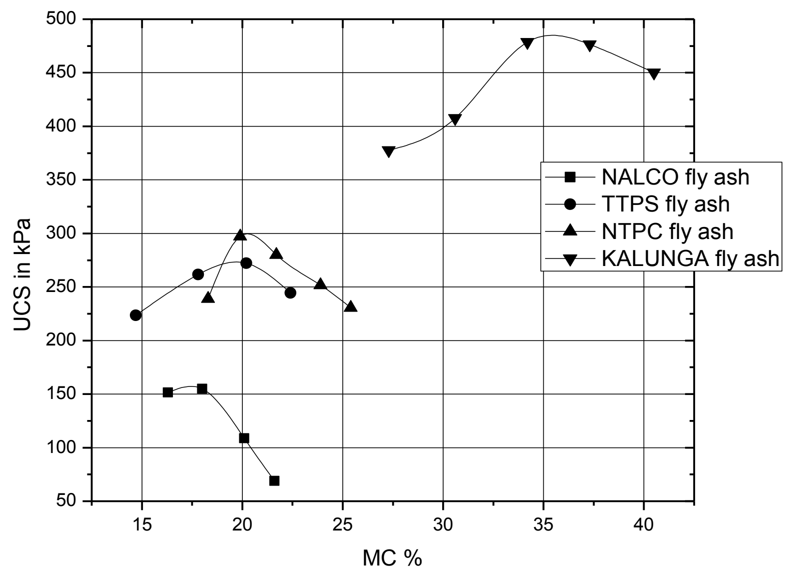


Fig4.11 Effect of UCS with change in MC

For all the fly ashes shown in Fig4.11, there is variation of UCS values with change in moisture content. The curve shows similar nature, that of fine sand. Same observations have also made by Das and Yudhbir (2005) for MC and UCS relationship.

Table4.12 Variation of UCS with MC, present study

NALCO		NTPC		TTPS		Kalunga	
Moisture content (%)	UCS kPa	Moisture content (%)	UCS kPa	Moisture content (%)	UCS kPa	Moisture content (%)	UCS kPa
16.3	151.55	18.3	239.03	14.7	223.57	27.3	377.50
18.0	154.84*	19.9	297.27	17.8	261.60	30.6	407.47
20.1 **OMC***	108.72	21.7	280.03*	20.2	272.23*	34.2	478.53*
21.6	68.83	23.9 **OMC***	251.67	22.4 **OMC***	244.42	37.3**OMC***	476.48
		25.4	230.62			40.5	450.19

From the above Table4.12 ,the unconfined compressive strength for as compacted test samples both on dry and wet of optimum for NALCO, NTPC, TTPS, Kalunga fly ashes have given. The dry side of optimum value gives more strength, then wet side of optimum .The variation of unconfined compressive strength with water content is similar to that of very fine sand. The result shows that for a given dry density, the apparent cohesion increases with degree of saturation and reaches a maximum. Additional saturation decreases the apparent cohesion.

4.4.4 Shear Strength From Direct Shear Box Test

For Direct shear Box test, the existence of c_u in compacted state is due to presence of capillary stresses for partial saturation. Under compacted condition, fly ash exhibits apparent cohesion. The values of ϕ_u reduced upon saturation with moisture content available. Fig4.12 indicate the failure envelops of fly ashes under as compacted conditions and Table4.13 lists the shear strength parameters of fly ashes from direct shear box test.

Table4.13 Shear strength parameters by Direct shear box Test, present study and Indian fly ashes *(data source Prakash and Sridharan 2007)

Source	As-compacted condition	
	C_u: kPa	ϕ_u: degrees
Kalunga	24.39	35.06
NTPC	23.27	34.93
TTPS	22.48	34.69
NALCO	21.69	33.18
Raibareli*	23	34
Korba*	22	34
Badarpur*	26	32
Ramagundam*	23	33

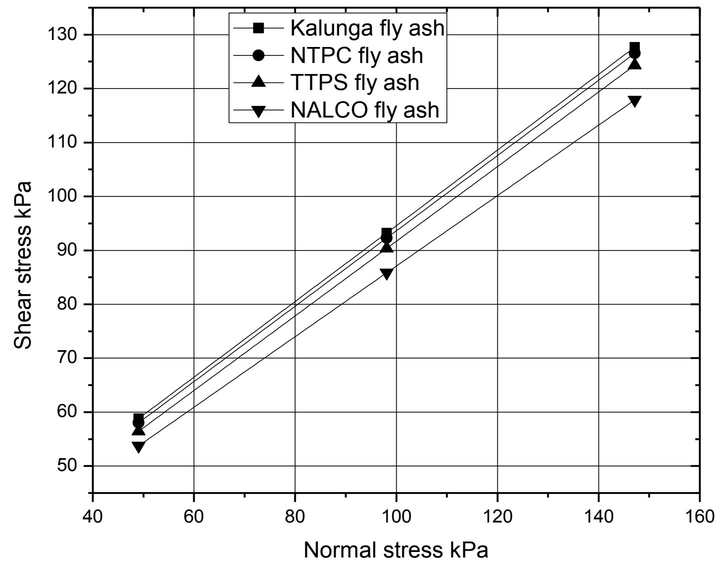
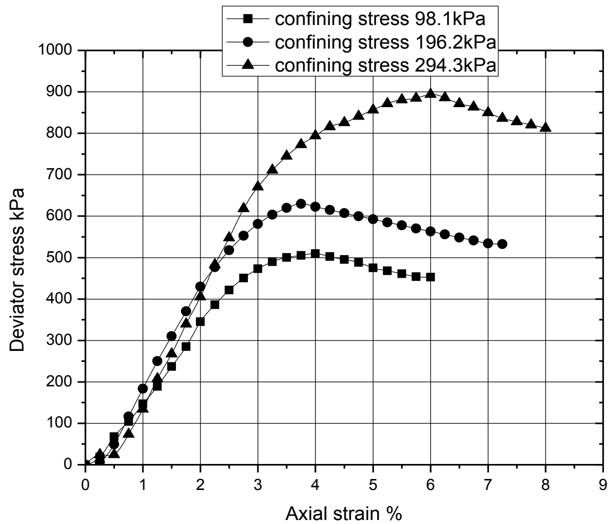


Fig4.12 Failure envelopes from direct shear box tests on fly ashes as in compacted state

From the present study, it found that the cohesion component is due to the capillary stress arises, which induced apparent cohesion. With increase in water content the frictional value decreases.

4.4.5 Shear Strength From Triaxial Shear Test

The most useful laboratory test conducted to determine the shear strength parameters of fly ash is the triaxial shear test. In this study an effort was also made to find out the effect of curing on the shear strength parameters of stabilized fly ash. At the optimum lime content the strength increases with days of curing.



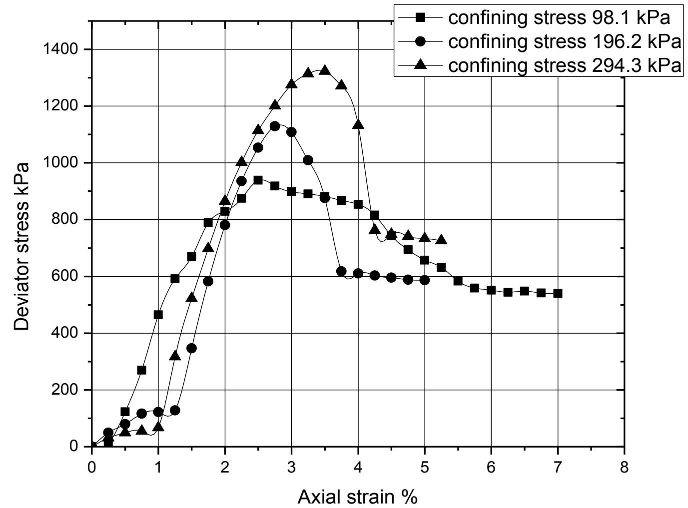
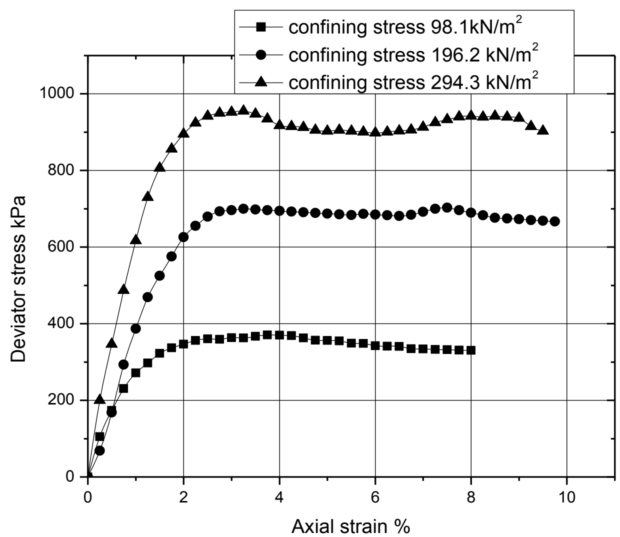


Fig4.13 Strain-stress curve of Kalunga fly ash with no curing

Fig4.14 Strain-stress curve of Kalunga fly ash with 7 days curin



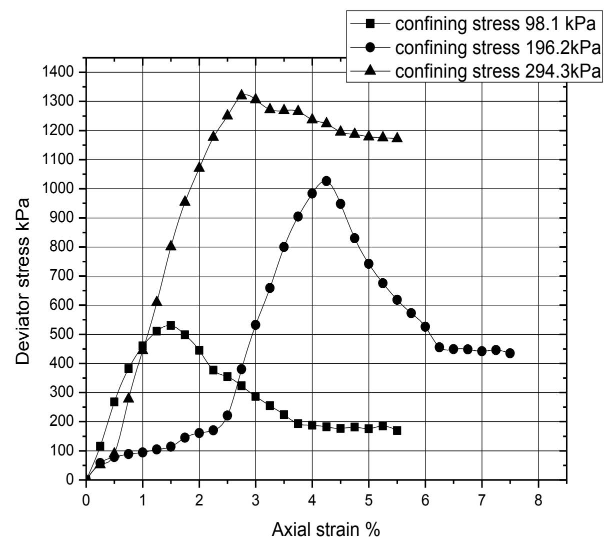
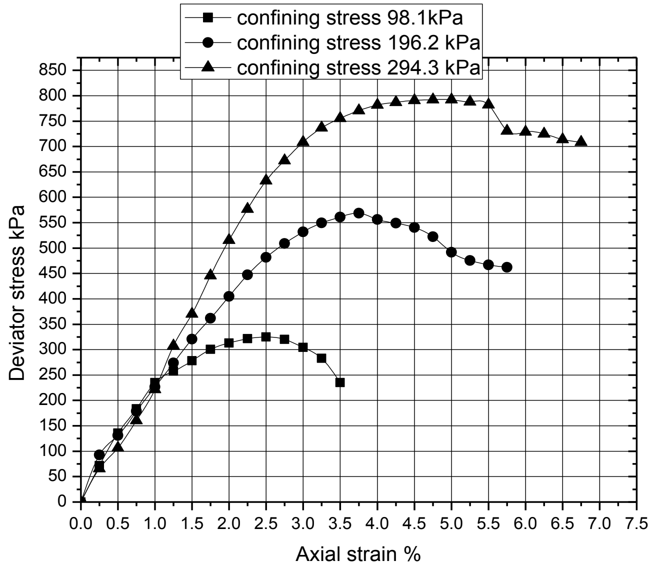


Fig4.15 Strain-stress curve of NALCO fly ash with no curing

Fig4.16 Strain-stress curve of NALCO fly ash with 7 days curing



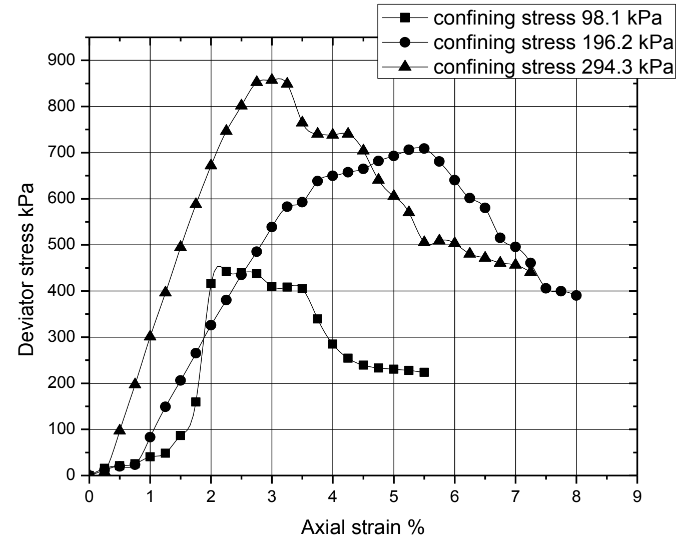
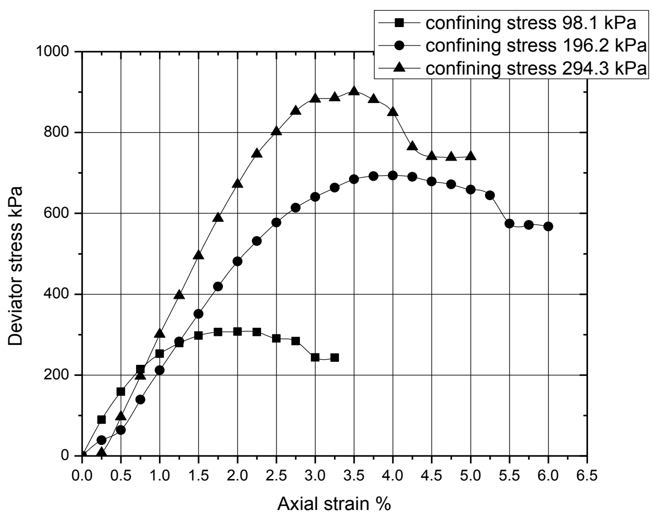


Fig4.17 Strain-stress curve of NTPC fly ash with no curing

Fig4.18 Strain-stress curve of NTPC fly ash with 7 days curing



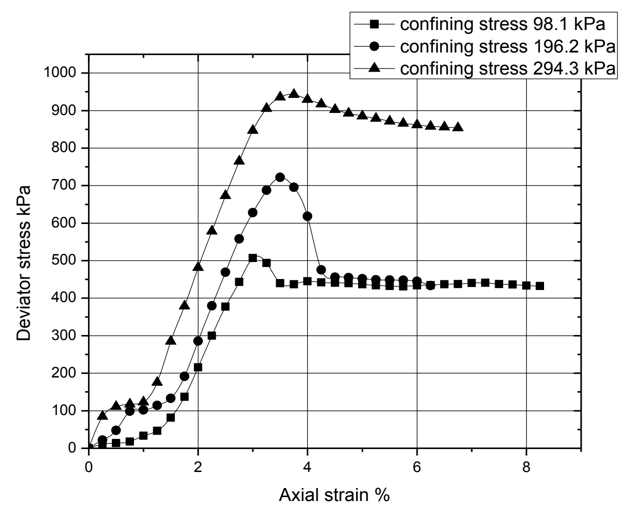


Fig4.19 Strain-stress curve of TTPS fly ash with no curing

Fig4.20 Strain-stress curve of TTPS fly ash with 7 days curing

The above curves Fig4.13-Fig4.20 show the variation of deviator stress with change in axial strain for the Kalunga, NALCO, NTPC and TTPS fly ash respectively.

Table4.14 Variation of undrained shear strength parameters of fly ashes with curing period,present study

Source	Fresh sample		7 days curing	
	C_u: kPa	ϕ_u: degrees	C_u: kPa	ϕ_u: degrees
NALCO	24.68	36.45	70.06	42.15
TTPS	25.39	35.31	71.61	40.87
NTPC	26.63	33.94	72.37	39.12
Kalunga	82.19	30.03	140.74	46.92

The shear parameters of the stabilized fly ash samples for immediate and after seven days of curing have shown in Table4.14. From the Table and curve shown above, shear parameters of NALCO fly ash has better values than TTPS fly ash, which is better than NTPC fly ash. After seven days curing the increase shear parameters had also same trend as it was before. Hence, it shows better lime reactivity or reactive silica present in NALCO fly ash than the other two fly ashes.

From the present study which gives the accurate values of shear parameters, gives the idea about apparent cohesion and pozzolanic effect. The fly ash study, for fresh fly ash sample the cohesion component is due to capillary stress and the angle of internal friction is due to both combined effect of pozzolanic effect and maximum dry density of fly ash achieve.

After seven days curing, the pozzolanic effect of fly ash plays important role for cohesion and angle of internal friction, which increases with addition of lime. Further the angle of internal friction is the main strength criteria for fly ashes, which is proportional to increase dry density.

Further the curve Fig4.21-Fig4.24 shown below the variation of deviator stress with change in axial strain with different days of curing. The increase in deviator stress value with curing for different fly ashes is due to its lime reactivity value.

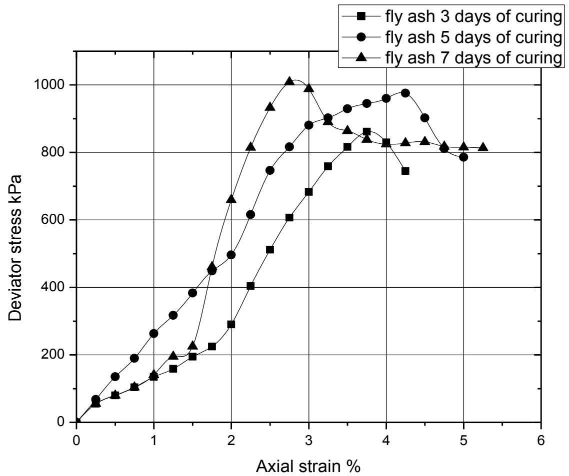


Fig4.21 Strain-stress curve of KALUNGA fly ash after 3,5,7 days of curing

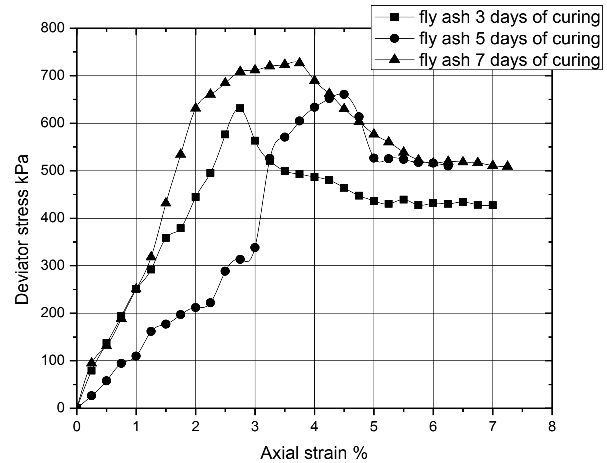


Fig4.22 Strain-stress curve of NALCO fly ash after 3,5,7 days of curing

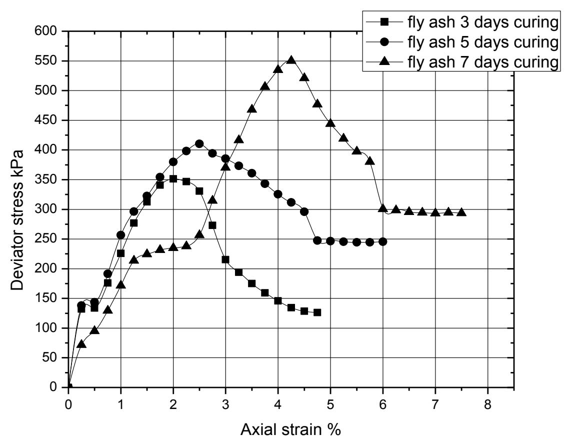


Fig4.23 Strain-stress curve of NTPC fly ash after 3,5,7 days of curing

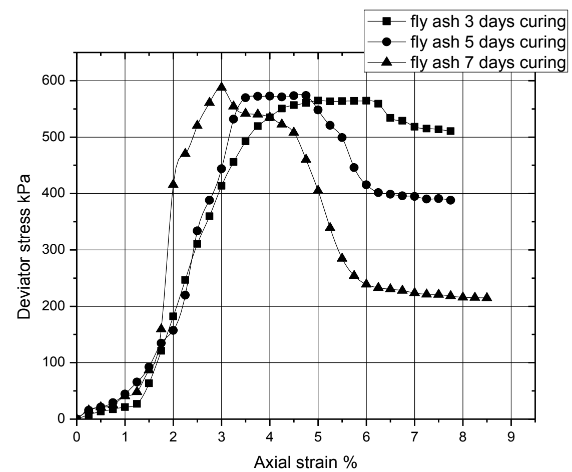


Fig4.24 Strain-stress curve of TTPS fly ash after 3,5,7 days of curing

Table4.15 Variation of Maximum Deviator stress value with change in curing period, present study

Source	3 days curing:Deviator stress kPa	5 days curing: Deviator stress kPa	7 days curing: Deviator stress kPa
NALCO	633.30	660.45	728.43
TTPS	564.77	573.71	588.04
NTPC	352.24	411.15	550.10
Kalunga	863.66	977.80	1011.42

Maximum Deviator Stress Vs Lime Content Curve

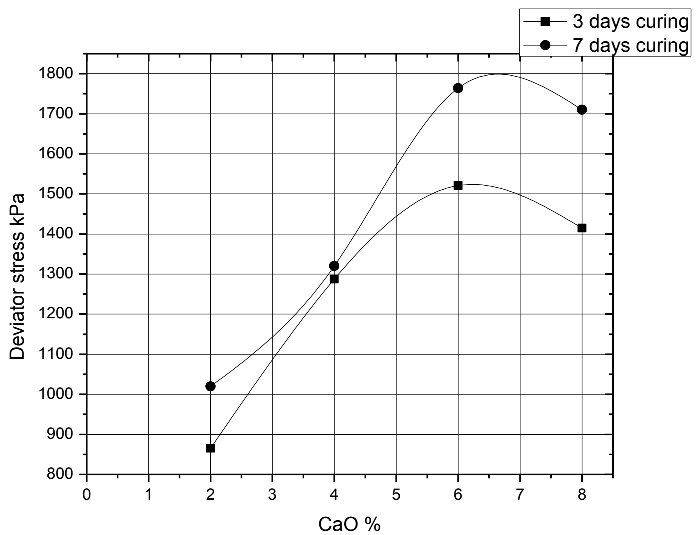


Fig4.25 Kalunga fly ash CaO vs Deviator stress curve

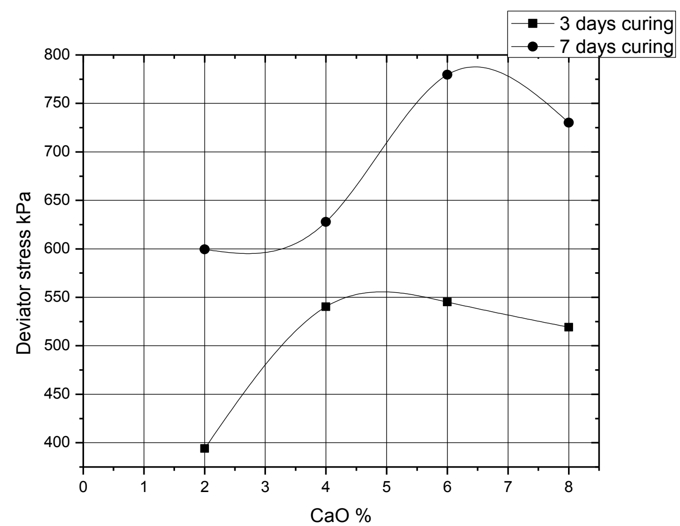
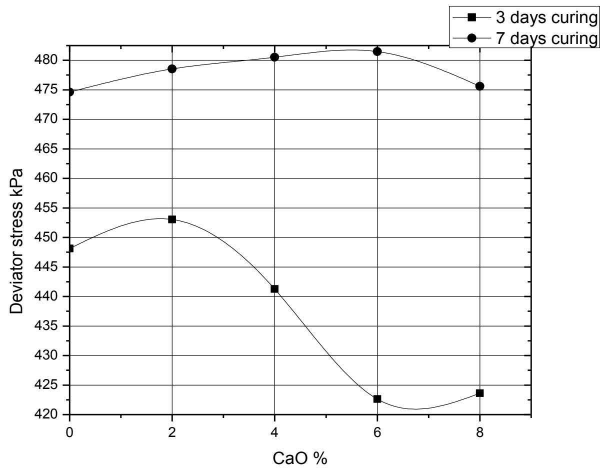


Fig4.26 NALCO fly ash CaO vs Deviator stress curve



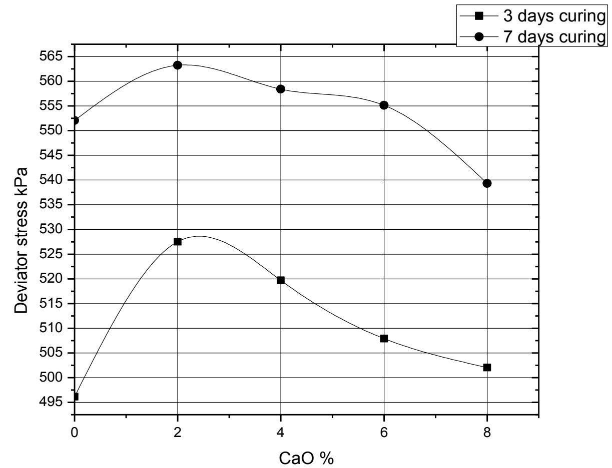


Fig4.27 NTPC fly ash CaO vs Deviator stress curve **Fig4.28 TTPS fly ash CaO vs Deviator stress curve**

From the above graph shown Fig4.25-Fig4.26, there is significant amount of increase in maximum deviator stress with increase in curing period. The increase deviator stress with increase curing period is more significant for 28 days curing, but however the increase in strength from three to seven days curing is due to pozzolanic effect of fly ash which depends upon the lime reactivity of fly ash with addition of lime. With the effects of curing and lime addition the maximum stress values increase considerably. The maximum value of deviator stress increased with curing period and with addition of lime mix. The above Fig4.25 shows Kalunga fly ash sample and Fig4.26 shows fly ash for NALCO sample for maximum deviator stress with lime addition whereas the NTPC and TTPS fly ashes are in between.

The above two Fig4.27 and Fig4.28 shows the variation of maximum deviator stress with lime for NTPC and TTPS fly ash respectively.

A considerable strength increases with increase of lime and curing period, drawn from triaxial compression test. Increase in curing period of lime treated fly ash specimen show improvement in the deviator stress value. However the gain in strength with curing period is more in initial days of curing which tends to decreases with increase in curing period.

Table4.16 Variation of Maximum Deviator stress value with change in CaO value and curing period,present study

Source	NALCO		Kalunga		NTPC		TTPS	
CaO: %	3 days curing	7 days curing	3 days curing	7 days curing	3 days curing	7 days curing	3 days curing	7 days curing
0					448.13	474.62	496.14	552.05
2	390.02	599.43	865.36	1019.47	453.04	478.54	527.53	563.26
4	540.17	627.67	1290.36	1316.98	441.26	480.50	519.68	558.41
6	545.08	779.63	1521.11	1764.26	422.62	481.48	507.91	555.13
8	519.12	730.08	1414.81	1710.07	423.61	475.60	502.02	539.30

From the Table4.16 above shown that, the increase trend in deviator stress value is more incase of NALCO fly ash followed by TTPS and NTPC fly ashes, which further illustrates the pozzolanic activity order.

4.4.6 CBR

The fly ashes, a fine-grained material, when placed at of Proctor maximum dry density and corresponding water content, exhibits capillary forces, in addition to friction resisting the penetration of the plunger and thus high values of CBR are obtained.

Table4.17 CBR values of fly ashes under unsoaked and soaked condition and some Indian fly ashes(data source Prakash and Sridharan 2007)

Source	CBR:%	
	Un soaked condition	Soaked condition
NTPC	6.94	0.66
NALCO	12.26	0.74
TTPS	5.29	0.86
Kalunga	22.49	5.73
Korba*	13.8	0.2
Vijayawada*	20.6	0.2
Ghatiabad*	18.9	0.2

From the Table4.17 it shows that the fly ash having more CBR values, this is because of more silt size particles and more fine sand size particles present from grain size distribution curve. The load- penetration curves for fly ash compacted at Proctor's maximum dry densities both unsoaked Fig4.29 and soaked Fig4.30 condition are as:

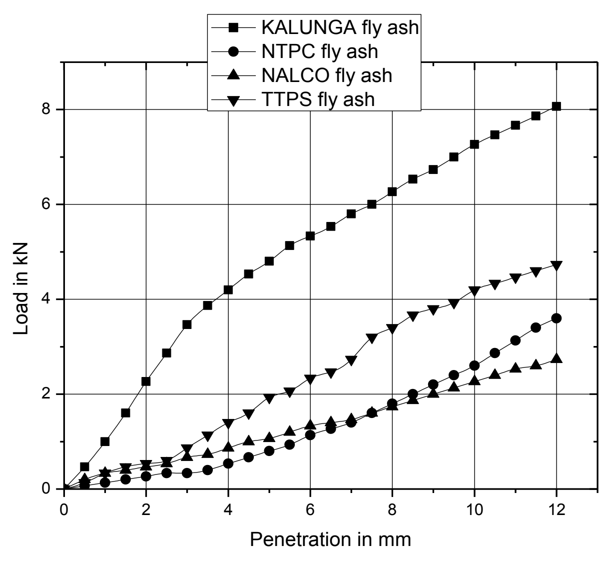


Fig4.29 CBR curves of fly ashes under unsoaked condition

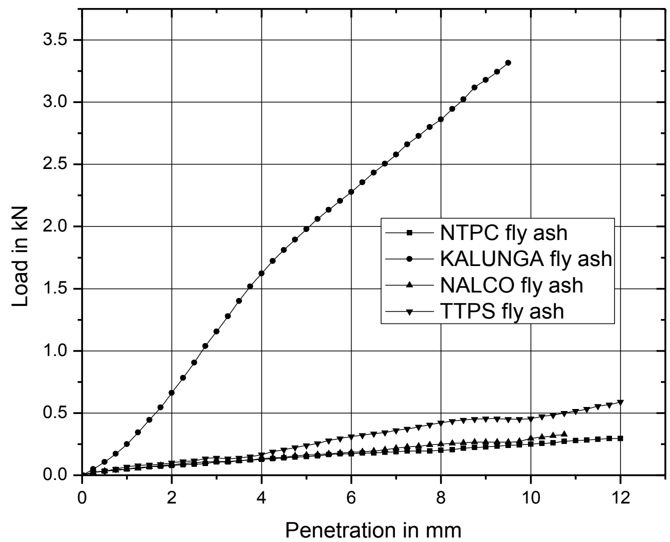


Fig4.30 CBR curves of fly ashes under soaked condition

On the contrary, when fly ash samples for four days soaked condition, under some placement condition, they exhibit low values of CBR. This can be attributed to further destruction of capillary forces under soaked condition.

4.4.7 Dispersiveness

According to double hydrometer test, the degrees of dispersion of four different fly ashes are as follows:

Table4.18 Classification of dispersive soils based on double hydrometer test results (data source Prakash and Sridharan 2007)

Source	Degree of Diepersion: %	Classification
TTPS	57.17	Highly dispersive
NTPC	83.33	Extremely dispersive
NALCO	38.33	Moderately dispersive
Kalunga	22.31	Non dispersive

From the Table4.18, it shows that the NTPC fly ashes are extremely dispersive due to, more percentage of fine particles are present followed by TTPS fly ash and NALCO fly ash. Hence this property plays vital role for mass application such as retaining wall structure, embankment and dykes. The Non dispersiveness of Kalunga fly ash particles is may be due to present of heavy metals.

4.4.8 Void Ratio

Table4.19 e_{max} and e_{min} values of fly ashes, present study

Source	e_{max}	e_{min}
Kalunga	2.391	1.130
NTPC	1.211	0.457
TTPS	1.380	0.545
NALCO	1.502	0.599

The relative e_{max} and e_{min} values of fly ash are as above Table4.19. The above values are like that, more pore spaces are present in Kalunga fly ash, which exhibits more e_{max} and e_{min} value. The other fly ashes are, varies according to their coarse silt size fraction. Table4.19 shows the present study of different fly ashes having different void ratio in maximum and minimum condition.

4.4.9 Liquid Limit Test

The experimental result of present, fly ashes Table4.20 have significant amount of water content at liquid limit. This variation is due to more silt size fraction present. If more silt size is present less will be liquid limit value. This is because, if some silt are added to the clay, the liquid limit value decreases

Table4.20 Liquid limit values of fly ashes, present study

Source	Water content:%
NTPC	32.86
NALCO	24.56
TTPS	28.44
Kalunga	47.01

Table4.20 shows the different liquid limit values of fly ashes for present study.

CHAPTER 5

Conclusion

5.1 Concluding Remark

Based on the present project work, the following conclusions can be made:

1. Fly ashes considered in the present study are of Class F fly ash with CaO containt less than 10%.
2. The NALCO fly ash contains cenospheres with small agglomerates whereas TTPS fly ash contains cenospheres with single cells without agglomerates, NTPC fly ash both contains cenospheres and plerospheres. Kalunga fly ash contains sub-rounded porous grains, irregular agglomerates and irregular porous grains of unburnt carbon.
3. The samples in the decreasing order of lime reactivities of fly ashes are NALCO, TTPS, NTPC and Kalunga samples respectively. Lime reactivity depends upon the presence of reactive silica.
4. Specific gravity found in present study are 2.41, 2.21, 2.13 and 2.04 for Kalunga , NALCO, TTPS , NTPC fly ash respectively. If more iron particles are present , specific gravity is more as in Kalunga fly ash but however specific gravity of fly ashes are small due to more number of cenospheres are present.
5. From the present study, the grain size distribution of fly ashes are uniformly graded silty particles and C_u value reduces with increase in finess of fly ash.
6. The free swell ratio for NALCO, NTPC, TTPS and Kalunga fly ash are -35.53%, -31.34%, -30.88% and -25.00% respectively.
7. The samples in the decreasing order of specific surface area are Kalunga, NALCO, TTPS and NTPC fly ashes respectively.
8. The fly ashes considered for the present study belong to the category of MLN-MIN.
9. The lime fixation point of Kalunga & NTPC fly ashes are 6% whereas NALCO & TTPS fly ashes are 7% respectively. UCS value increased when lime increased upto lime fixation point.
10. From the present study fly ashes compacted dry side of optimum give more strength than wet side of optimum.

11. From triaxial shear test, samples with shear parameter values in decreasing order are Kalunga, NTPC, TTPS and NALCO fly ash samples. Fly ash exhibits, more of its shear strength from internal friction and exhibits some amount of apparent cohesion.
12. The decreasing order of CBR values for the present study are in order of Kalunga, NALCO, NTPC and TTPS fly ash samples respectively. Low value of CBR under soaked condition is due to destruction of capillary forces under soaked condition. This indicates that CBR value of compacted fly ash is very susceptible to degree of saturation.
13. The decreasing order of degree of dispersions are in order of NTPC, TTPS , NALCO and Kalunga fly ash samples .
14. Its low specific gravity, freely draining nature, ease of compaction, good frictional properties, pozzolanic activity etc can be gainfully used for construction of embankment, roads and fill behind a retaining structure.

5.2 Scope for Further Study

Though fly ashes are being used in different geotechnical engineering application, but there is not a standard classification scheme for the same and the present classification scheme does not show the true difference between the properties.

Hence, there is a need to characterize fly ashes from different sources and at different conditions of the plant.

A better classification scheme should be framed considering chemical, mineralogical along with the particle size consideration of the fly ash.

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